

GLOSSARY

Abyssal plain

Flat areas of the ocean basin floor which slope less than 1 part in 1000. These were formed by turbidity currents which covered the preexisting topography. Most abyssal plains are located between the base of the continental rise and the abyssal hills. The remainders are trench and abyssal plains that lie in the bottom of deep-sea trenches. This latter type traps all sediment from turbidity currents and prevents abyssal plains from forming further seaward, e.g. much of the Pacific Ocean floor.

Abyssopelagic zone

One of five vertical ecological zones into which the deep sea is sometimes divided. There is a pronounced drop in the number of species and the quantity of animals as one passes into this zone. It is separated from the overlying bathypelagic zone by the 4°C isotherm and from the underlying hadopelagic zone at about 6000 meters. The distinction between pelagic and benthic species can be difficult to ascertain in this zone.

Acoustic tomography

The inference of the state of the ocean from precise measurements of the properties of sound waves passing through it. This technique takes advantage of the facts that the properties of sound in the ocean are functions of temperature, water velocity and other salient oceanographic properties and that the ocean is nearly transparent to low-frequency sound waves. These felicitous circumstances combine to allow signals transmitted over hundreds to thousands of kilometers to be processed with inverse methods to obtain estimates of large-scale fields of ocean properties. An especially advantageous feature of this method is that, given the 3000 knot speed of sound in the ocean, reasonably synoptic fields can be constructed. The chief problems presently encountered in this field are those related to engineering sufficiently accurate transmitters and receivers for the task.

ADCP

An Acoustic Doppler Current Profiler is often referred to the acronym ADCP. Scientists use the instrument to measure how fast water is moving across an entire water column. An ADCP anchored to the seafloor can measure current speed not just at the bottom, but also at equal intervals all the way up to the surface. The instrument can also be mounted horizontally on seawalls or bridge pilings in rivers and canals to measure the current profile from shore to shore, and to the bottoms of ships to take constant current measurements as the boats move. In very deep areas, they can be lowered on a cable from the surface.

ADCPs that are bottom-mounted need an anchor to keep them on the bottom, batteries, and an internal data logger. Vessel-mounted instruments need a vessel with power, a shipboard computer to receive the data, and a GPS navigation

system (so the ship's own movements can be subtracted from the current data). ADCPs have no external read-out, so the data must be stored and manipulated on a computer. Software programs designed to work with ADCP data are available. The ADCP measures water currents with sound, using a principle of sound waves called the Doppler Effect. A sound wave has a higher frequency, or pitch, when it moves to you than when it moves away.

The ADCP works by transmitting "pings" of sound at a constant frequency into the water. (The pings are so highly pitched that humans and even dolphins can't hear them, mostly 150 or 300 kHz). As the sound waves travel, they ricochet off particles suspended in the moving water, and reflect back to the instrument. Due to the Doppler Effect, sound waves bounced back from a particle moving away from the profiler have a slightly lowered frequency when they return. Particles moving toward the instrument send back higher frequency waves. The difference in frequency between the waves the profiler sends out and the waves it receives is called the Doppler shift. The instrument uses this shift to calculate how fast the particle and the water around it are moving.

Sound waves that hit particles far from the profiler take longer to come back than waves that strike close by. By measuring the time it takes for the waves to bounce back and the Doppler shift, the profiler can measure current speed at many different depths with each series of pings.

The ADCP measures the ocean current velocity continuously over the upper 300 m of the water column, usually in 8 m depth increments. It is also used to estimate the abundance and distribution of biological scatterers over the same depth range and in the same depth increments. The back-scatterers have to be half a wavelength across to be seen by the acoustics, which is about 1 cm for 150 kHz. A dense cloud of smaller particles can also reflect the sound. The 'particles' are, of course, often planktonic animals, and so ADCP is now being used quite extensively by biologists to carry out synoptic surveys of pelagic communities. ADCP data collection requires that four instruments work together. These are the ADCP itself, the ship's gyrocompass, a GPS receiver, and a GPS Attitude Determination Unit (ADU).

Advantages:

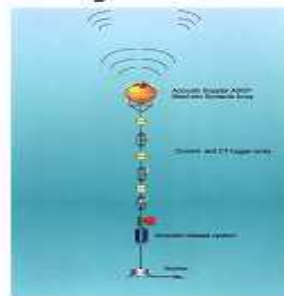
- In the past, measuring the current depth profile required the use of long strings of current meters. This is no longer needed.
- Measures small scale currents
- Unlike previous technology, ADCPs measure the absolute speed of the water, not just how fast one water mass is moving in relation to another or relative currents.
- Measures a water column up to 1000m long

Disadvantages:

- High frequency pings yield more precise data, but low frequency pings travel farther in the water. So scientists must make a compromise between the distance that the profiler can measure and the precision of the measurements.
- ADCPs set to "ping" rapidly also run out of batteries rapidly
- If the water is very clear, as in the tropics, the pings may not hit enough particles to produce reliable data
- Bubbles in turbulent water or schools of swimming marine life can cause the instrument to miscalculate the current
- Users must take precautions to keep barnacles and algae from growing on the transducers.



Deep Ocean current mooring with ADCP



Adiabatic change

Involving or allowing neither gain nor loss of heat.

Adiabatic compressibility

A quantity arising from taking derivatives of the density in the representation of the equation of state. It is defined by

$$\kappa = \frac{1}{\rho} \left(\frac{\partial \rho}{\partial p} \right)_{\theta, S}$$

where ρ is the fluid density, p the pressure, θ the potential temperature, and S the salinity.

Age of water

The elapsed time since a given water mass was last at the sea surface.

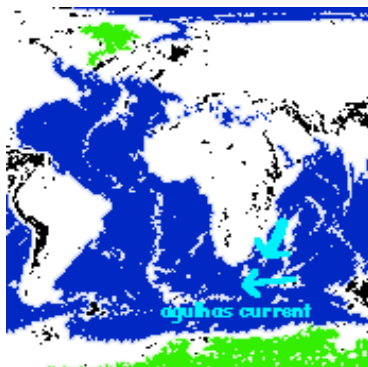
Agulhas Basin

An ocean basin located off the southern tip of Africa at about 43° S in the South Atlantic Ocean. It includes the Agulhas Abyssal Plain.

Agulhas Current

The Western Boundary Current in the South Indian Ocean south of 30° S. The southern Agulhas Current flows southwestward as a narrow jet along a steep continental slope, and is normally pinned to within 10-15 km of its mean position at latitudes 28.5-34° S. Large meanders - called the Natal pulse - can sometimes occur within this region. These extend an average of 170 km offshore with downstream propagation rates of about 21 cm s⁻¹, with the rates decreasing to 5 cm s⁻¹ as the continental shelf broadens near 34° S. At this point the current separates from the coast and continues southwestward along the Agulhas Bank, where many meanders, plumes and eddies exist. The maximum transport of the Agulhas occurs in the vicinity of Agulhas Bank, where transport estimates range from 95 to 136 Sv. The core of the current has been defined as where surface velocities exceed 100 cm s⁻¹, with the core averaging about 34 km wide with a mean peak speed of 136 cm s⁻¹ (with a greatest peak speed of 245 cm s⁻¹).

At around 36° S the Agulhas leaves the continental shelf and develops oscillations of increasing amplitude, eventually retroflecting back toward the Indian Ocean in the region of 16-20° E as the Agulhas Return Current. The retroflexion loop usually encloses a pool of Indian Ocean surface water south of Africa whose temperature is more than 5° warmer than South Atlantic surface water at similar latitudes. The core of the Return Current infrequently passes over the Agulhas Plateau.



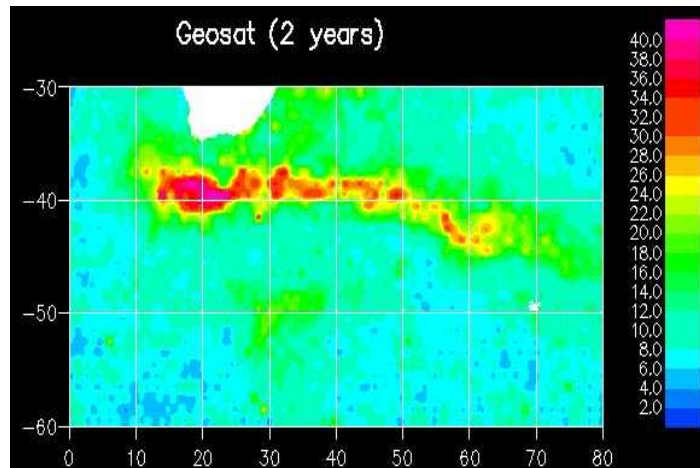
In order to sail the South Atlantic and round the tip of Africa, Portuguese sailors had to confront two powerful ocean currents: the **Agulhas** and **Benguela** currents. The warm **Agulhas** runs south and west from the Indian Ocean pushing against the near-freezing waters of Antarctica, before meeting the cold Benguela current off the Cape of Good Hope. The second swiftest current in all the world's oceans, the **Agulhas** is deadlier than the swiftest current (the Gulf Stream) for two reasons. First one is one of its branches surges through a narrow passageway between Madagascar and Mozambique on the east coast of South Africa (downward arrow on map). Furthermore its waters rush from north to south--the opposite direction from which Portuguese ships needed to travel in order to round the tip of Africa. In nearly a thousand years of crossing the Indian Ocean, neither the Arabs nor Persians nor Arabs nor the fifteenth-century Chinese Star Fleet had ever navigated the Mozambique Channel, even sailing with the Agulhas Current. To sail against the Agulhas Current is even trickier than sailing with it. Only a *very narrow band of water* northward through the current (up the east coast of Africa to reach the Indian Ocean) boats had to take back and forth in a very narrow band of water--in which submerged sharp rocks abound--and modern shipping trawlers with sophisticated navigational instruments still wreck themselves today. The picture shows the rocks at the southern tip of Africa today with the Agulhas current just beyond.

Gale force winds (up to 180 kilometers per hour) are common in the Spring (September through November). Even more frightening are the deadly changes that occur when the winds shift direction. When the winds begin to blow from the West and Southwest (the opposite direction from the current), monster waves (up to five stories high) is known to occur. There is no way to survive from such rogue waves, for even the largest vessels plummet to the ocean floor without a trace. After **Bartholomew Dias** successfully sailed the treacherous intersection of the **Benguela** and **Agulhas** current (the Cape of Good Hope), it took three separate Portuguese voyages between 1486 and 1497 to learn to navigate successfully through the Agulhas current, travelling in the opposite direction. Each separate fragment on the map represents a separate voyage through the Mozambique Channel sailing against the Agulhas current. Cape Agulhas is the southern most point of the African continent today. It's shown below.

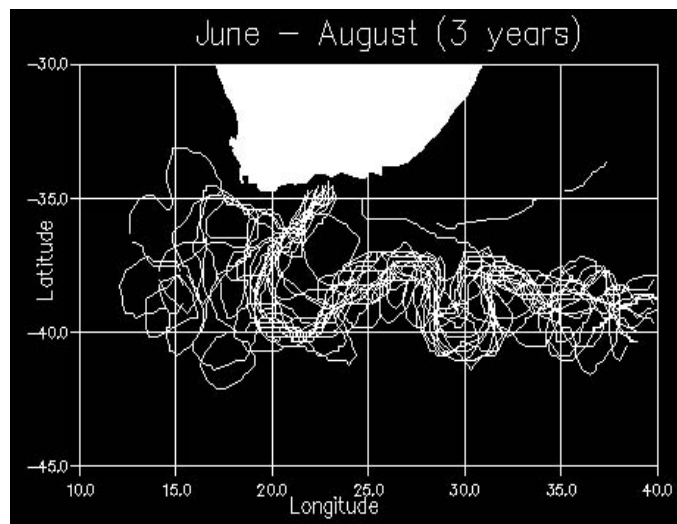


The icy Benguela current moves north from the Southern Ocean (around Antarctica) and flows northwards along the West Coast of Africa. Along with the accompanying winds the Benguela current reaches as far as southern Angola, making it extremely difficult to travel southward along the Atlantic Coast. Where the icy Benguela meets the warm, south- and west-flowing Agulhas, there is a rich sea life beneath the surface, but tremendous turbulence above. South African folklore considers the meeting of the two currents--the cold Benguela and the warm Agulhas (roughly off the Cape of Good Hope) as the place where the two oceans meet.

The currents at the African shore are interesting. During the northeast monsoon period (November to March) the SEC, when it reaches the African shore, supplies both the ECC to its north and the Agulhas Current flowing south. This current is deep and remarkably narrow, probably only 100 km wide, and flows south close to the African shore with a transport reported to average 50 Sv and to rise to 80 Sv at times. When it reaches the southern tip of Africa, the current turns east into the Circumpolar Current. During the southwest monsoon (May to September), the component of the SEC, which turns north, supplies the Somali Current up the east coast of Africa. This current is notable for its high speeds of up to 200 cm/s, which are comparable to those of the Florida Current, and it has a transport of about 65 Sv, most of it in the upper 200 m. The South Equatorial Current, the Somali Current and the Monsoon Current then comprise a strong wind driven gyre in the northern Indian Ocean. Strong upwelling occurs at this time along the Somali and Arabian coasts. A lot has been studied about the Agulhas Current, its retroflexion and its contribution in the form of eddies to the circulation in the South Atlantic. An infrared satellite image representing the Agulhas Current, its eddies and retroflexion was presented below. The RMS variability of the sea surface height from 2 years of GEOSAT data shows an interesting maximum band to the south and east of Africa representing the Agulhas retroflexion.



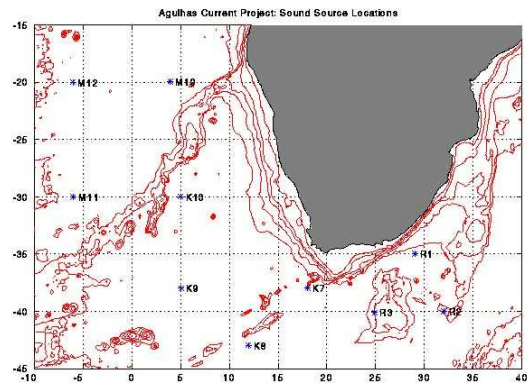
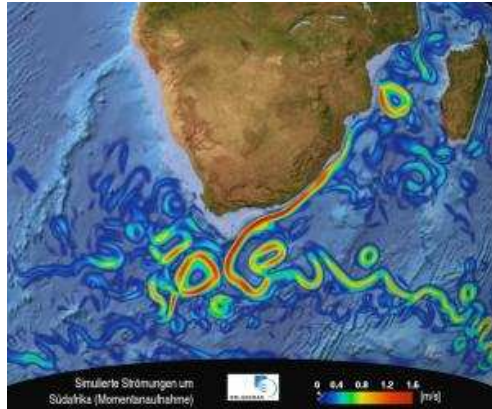
GEOSAT RMS Surface height variability for Dec. 1986 through Nov. 1988.



Infrared boundary of the Agulhas Currnet June-Aug (3 years)

The Gesosat results are confirmed by AVHRR thermal data. The plots below (produced from analysis by Eric Chassignet) show the location of the thermal edge of the Agulhas Current System over a 3 year period. Once again, the lower plot (austral winter, shows more activity to the west than does the upper one for the summer season.

Agulhas eddies:



Bottom topography in the Agulhas region.

This narrow band of maximum surface height variability abruptly increases in amplitude just to the west of about 27 °E. It is interesting that there are a couple of rather “tall” topographic features at about this longitude that could be contributing to the unstable growth of Agulhas eddies in this area.

Agulhas Front (AF)

A strong subsurface to intermediate depth front beneath the upper 100-150 m that originates at around 20°-25° E below the southern tip of Africa. It extends to between 65°-90° E where it merges with the Southern Subtropical Front in the Indian Ocean sector of the ACC. The chief identification criterion is usually the depth range of the 10° isotherm, about 300-800 m south of Africa at 16°-27° E. This range shrinks to about 400-650 m to the east in the Kerguelan-Amsterdam passage, indicating the gradual weakening of the AF. A thermocline on the warm side of the AF in the 150-300 m layer is another useful identification criterion. This thermocline cools and freshens to east, ranging from 17°-18° C/35.5-35.6 at 20° E to 12°-14° C/35.2-35.4 at 70° E.

Agulhas Undercurrent

A current flowing beneath the Agulhas Current. LADCP measurements indicate the core is centered around 1200 m, against the continental slope and directly below the surface core of the southwestward flowing Agulhas Current. Maximum velocities of 30 cm/s to the northeast are observed in the undercurrent, and its volume transport is 6 Sv, about a tenth that of the overlying Agulhas.

Air-sea interaction

The processes that involve the transfer of energy, matter, and momentum between the atmosphere and the ocean. This is one of the least well understood areas of physical oceanography, with the theory inadequate and the data sparse. Specific areas with glaring gaps include the interaction of the wind and surface waves, the parameterization of subgrid scale processes in large-scale circulation models, and the transfer of gases across the air-sea interfaces.

Albedo

The proportion of incident radiation reflected by a surface. About 30% of the incoming solar energy is reflected back to space from the earth, of which 25% is reflected by clouds and 5% by the surface or by atmospheric molecules or suspended particles. The clouds and atmospheric gases and particles absorb 25% of the incident radiation with the remainder absorbed at the surface.

Aliasing

A phenomenon encountered when sampling a continuous function to produce values at discrete points. If the sampling frequency isn't high enough to resolve the highest frequency signal present in the continuous function, then the high frequency information above the sampling frequency will appear as a false enhancement of (or, equivalently, be aliased onto) a related lower frequency in the computed power spectrum.

Alkalinity

A property of sea water operationally defined as the excess positive charge to be balanced by CO_3^{3-} and HCO_3^{3-} ions. The carbonate ion content of any unit of sea water is equal to its alkalinity (i.e. excess positive charge) minus its total dissolved carbon content.

Andaman Sea

A body of water in the northeastern corner of the Indian Ocean that lies to the west of the Malay Peninsula, the north of Sumatra, the east of the Andaman Islands, and the south of the Irrawaddy Delta in Burma. It stretches about 650 km from west to east and 1200 km from north to south. The Andaman communicates with the westward lying Bay of Bengal through several channels between the chain of islands that stretches along 93° E., including the Preparis (200 m deep), Ten Degree (800 m deep) and Great (1800 m deep) Channels. It is connected with the Australasian Mediterranean Sea via the Malacca Strait between Thailand and Sumatra. It has been variously estimated to have an area of 600,000 to 800,000 km² and an average and maximum depth of, respectively, 870-1100 m and 4200 m.

The temperature of the surface waters fluctuates mildly from a monthly average of about 30°C in the summer months to one of about 27.5 in the winter months. They drop off with depth to about 5°C and 2000 m. The surface salinities exhibit strong seasonal variations due to an extremely large freshwater influx from the Irrawaddy and Salween rivers during monsoon season. In the northern part the salinities range from about 20 during the monsoon months from June to November to about 32 from December to May. This grade to a fairly constant 33.5 in the southwest end and to a maximum of about 35 near 1500 m depth.

The steadiest current is the inflow through the Malacca Straits, averaging around 1/3-2 knots through the year. The monsoons control the currents elsewhere, driving inflow waters from the Bay of Bengal through the western channels from June to August during the southwest monsoon. This also pushes the Malaccan inflow

against the Sumatran coast and forces some Andaman sea water through the Straits. When these winds die southwestward currents gradually form that are maintained and enhanced by the northeast monsoon from December through February. A more sudden shift is seen from March through May when the southwest monsoons begins anew.

Antarctic Bottom Water (AABW)

A type of water in the seas surrounding Antarctica with temperatures ranging from 0 to -0.8°C , salinities from 34.6 to 34.7, and a density near 27.88. ABW is formed in the Weddell and Ross Seas. This is the densest water in the free ocean, with the only denser waters being found in regional sill basins such as the Norwegian Sea or the Mediterranean. It is overlain by Antarctic Circumpolar Water (AACW) at a depth of 1000 to 2000 m [3000 m (Tchernia)] and overlies Weddel Sea Bottom Water (WSBW) in some locations.

The flow of AABW in the tropical Atlantic is described as: About one-third of the northward flowing AABW at 10°S (4.8 Sv) and at 5°S (4.7 Sv) west of about $31^{\circ}30'\text{W}$ enters the Guiana Basin, mainly through the southern half of the Equatorial Channel at 35°W (1.5-1.8 Sv). The other part recirculates and some of it flows through the Romanche Fracture Zone into the eastern Atlantic. In the Guiana Basin, west of 40°W , the sloping topography and the strong, eastward flowing deep western boundary current might prevent the AABW from flowing west: thus it has to turn north at the eastern slope of the Ceara Rise (2.2 Sv). At 44°W , north of the Ceara Rise, AABW flows west in the interior of the basin in a main core near $7^{\circ}15'\text{N}$ (1.9 Sv). A net return flow of about 0.5 Sv was found north of $8^{\circ}43'\text{N}$. A large fraction of the AABW (1.1 Sv) enters the eastern Atlantic through the Vema Fracture Zone, leaving only 0.3 Sv of AABW for the western Atlantic basins.

Antarctic Circumpolar Current (ACC)

A major eastward flowing current that circles the globe in the Southern Ocean. It is principally driven by surface wind stress, although there is a significant thermohaline component that is not yet well understood. In the way of vorticity dynamics a simple Sverdrup balance with dissipative mechanisms of form drag by bottom topography and lateral dissipation in western boundary layers has been found consistent with the data. The present best estimates of its transport through Drake Passage give a net mean transport of 125 Sv (with a standard deviation of 10 Sv) above 2500 m.

The transport of the ACC is concentrated in two current cores separated by a transition zone with surface water characteristics intermediate between those found to the south in the Antarctic Zone and to the north in the Subantarctic Zone, with the transition zone being known as the Polar Frontal Zone. The maximum

geostrophic surface speeds in these cores have been calculated as 25-45 cm s⁻¹ in Drake Passage.

There is also considerable mesoscale variability in the ACC region due to instabilities causing both cold and warm core rings to be shed. These eddies have been found to have spatial scales varying from 30 to 100 km, surface velocities typically 30 cm s⁻¹ or greater, and are vertically coherent from surface to bottom. The regions of highest variability have been found to be correlated with prominent topographic features on the sea floor.

The ACC is a region of complicated and large meridional heat flux, with a mean ocean heat loss to the south estimated at about 0.45 petawatts due to ocean-atmosphere heat exchange and equatorward Ekman transport. This is thought to be balanced by the import of heat via eddy processes and deep boundary currents, although the proportions are known only vaguely as yet.

Antarctic Circumpolar Water (AACW)

A type of water in the seas surrounding Antarctica with temperatures ranging from 0 to 0.8°C, salinities from 34.6 to 34.7 ppt, and a depth range from a few hundred meters to about 1000-2000 m [3000 m (Tchernia)] It is formed from a mixture of overlying North Atlantic Deep Water (NADW) and underlying (at 1000-2000 m) Antarctic Bottom Water (AABW). It has a temperature maximum around 500-600 m and a salinity maximum between 700-1300 m. This was originally called Warm Deep Water (WDW) by Deacon, but renamed AACW by Sverdrup.

Antarctic Divergence

In physical oceanography, a region of rapid transition located in the Antarctic Zone of Southern Ocean between the Continental Water Boundary to the south and the Polar Front to the north. It can be distinguished hydrographically by a salinity maximum below about 150 m caused by the upwelling of water of high salinity, i.e. North Atlantic Deep Water. Above this the maximum is blurred by high precipitation and the melting of ice. Its position corresponds reasonably well to the demarcation between the east and west wind drifts which, in the light of Ekman dynamics, at least partially explains its divergent nature.

Antarctic Intermediate Water (AAIW)

In physical oceanography, a type of water mass in the Southern Ocean thought to originate mainly through convective overturning of surface waters during winter west of South America, after which it is injected into the subtropical gyre and fills the southern subtropics and tropics from the east.

In the Atlantic, the densest Subantarctic Mode Water (SAMW) found in the Subantarctic Zone between the Subantarctic Front and the Subtropical Front is thought to be the primary precursor to AAIW, although some postulate substantial

input across the Subantarctic Front. The AAIW in the South Atlantic originates from a surface region of the circumpolar layer, especially in the northern Drake Passage and the Falkland Current loop. AAIW from the Indian Ocean is added to the Atlantic AAIW via Agulhas Current leakage. The AAIW is recognized by a subsurface oxygen maximum and a salinity minimum north of about 50°S, although the oxygen maximum becomes weak north of 15°S. The oxygen maximum is found at a slightly lower density than the salinity minimum.

The salinity minimum is found at about 300 m near the Subantarctic Front at around 45°S, descends northward to 900 m at 30°S near the subtropical gyre center, and rises again to 700 m at the equator. The AAIW spreads to the North

Atlantic, identified by a salinity minimum near the equator at a σ_θ value of about 27.3. This minimum has been found to 24°N, although traces of AAIW can be followed as far north as 60°N. AAIW is characterized by a temperature near 2.2° C and a salinity around 33.8 near its formation region, but erodes by the time it reaches the Subtropical Front to values closer to 3° C and 34.3.

Antarctic Surface Water (AASW)

In physical oceanography, a water mass in the Antarctic Zone of the Southern Ocean AASW is found in the upper 200 m south of the Polar Front (PF) and is cold, fresh, and high in oxygen and nutrients relative to the subantarctic surface waters, although it is high in nutrients compared to underlying waters. The most easily distinguishable characteristics of AASW in summer sections is a intense temperature minimum at about 200 m that marks the base of the winter mixed layer. The water around this minimum is also commonly known as Winter Water, and ranges from 50 m deep in the Weddell Gyre to nearly 1000 m just north of the PF. It is characterized by very low temperatures ranging down to the freezing point of -1.9° C and low salinities as the result of ice melting in the summer in the upper 100-250 m of the water column.

Anticyclonic

The direction of rotation around a center of high pressure. This is clockwise in the northern hemisphere and counter-clockwise in the southern.

Arabian Sea

A regional sea, centered at approximately 65° E and 15° N, that is bounded by Pakistan and Iran to the north, Oman, Yemen and the Somali Republic to the west, India to the east, and the greater Indian Ocean to the south. The southern boundary, from an oceanographic point of view, runs from Goa on the Indian coast along the west side of the Laccadive Islands to the equator, and thence slightly to the south to near Mombasa on the Kenyan coast. It covers an area of about 7,456,000 km².

The flow pattern in the Arabian Sea is seasonal, changing with the monsoon winds. In the northeast monsoon season (from November until March) the winds are light and the surface circulation is dominated by a weak westward, counter-

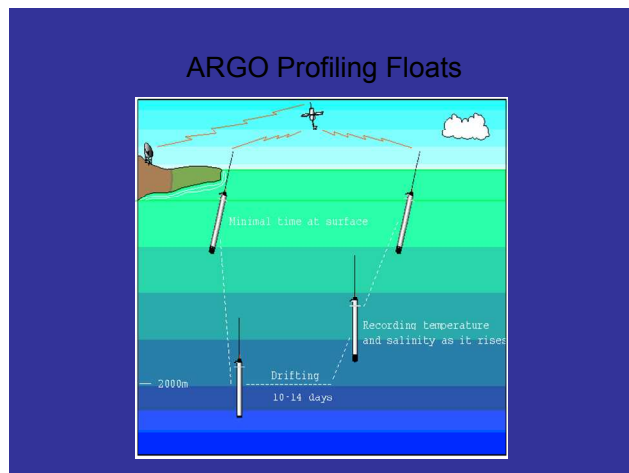
monsoon flow (as an extension of the North Equatorial Current) with velocities usually under 0.2 m/s. This pattern starts in November with water supplied by the East Indian Winter Jet flowing around the southern tip of Indian and heading northwestward along the western Indian shelf.

Westward flow dominates in the southern parts until late April with the north gradually shifting into a weak anticyclonic pattern. With the advent of the southwest monsoon in April, the Somali Current and its northward extension, the East Arabian Current, both develop into strong, northeastward flowing currents by mid-May. The anticyclonic pattern in the eastern Arabian Sea is simultaneously being gradually replaced by a moderate eastward flow composed of extensions of the Somali Current and the Southwest Monsoon Current. This pattern lasts for 4-5 months, peaking in June and July at about 0.3 m/s and weakening rapidly in October as the eastward flow around southern India once again pushes northwestward.

From May to September there is strong upwelling in the East Arabian Current along Oman, accompanied by a 5°C or more lowering of coastal temperatures due to the cold upwelling water. This upwelling isn't as conducive to primary production as elsewhere due to the rapidly moving current removing much of the upwelled additional biomass before it can be utilized.

Argo

A global array of 3,000 free-drifting profiling floats that will measure the temperature and salinity of the upper 2000 m of the ocean. This will allow the continuous monitoring of the climate state of the ocean. Once the full network is in place in 2002 or thereabouts, Argo will provide 100,000 T/S profiles and reference velocity measurements per year from floats distributed over the oceans at about a 3 degree spacing. The floats will cycle to 2000 m depth every 10 days, with a planned 4-5 year lifetime for individual instruments. All data will be made publicly available in near real-time via the GTS, and in scientifically quality-controlled form within a few months.



ASHSW

Abbreviation for Arabian Sea High Salinity Water.

Atoll

One of the three geomorphologically distinct types of coral reefs, the other two being fringing reefs and barrier reefs. An atoll is an annular reef formed around a subsiding volcanic island, leaving a lake at the center. For example, Addu atoll in the Indian Ocean.

Azoic zone

Term used to describe the part of the deep sea thought lifeless in the mid-19th century. It was thought that the abyss was filled with a thick layer of 4°C (since sea water was thought to be densest at that temperature), motionless water which, combined with the tremendous pressures and absence of sunlight, virtually guaranteed an absence of life. The term was coined by the naturalist Edward Forbes in the 1840s who, after dredging for life forms in various regions, postulated eight bands or depth zones, each characterized by a particular assemblage of animals. These zones extended to a lower limit he set at about 300 fathoms below which the existence of life was highly unlikely. His results (and therefore perceptions) on this issue were skewed by an 1841 cruise in the eastern Mediterranean where he dredged for life forms at depths up to 230 fathoms in what is now known to be a relatively barren area. The contrast of this with the rich hauls he made in shallower waters around England led to his thinking the abyss devoid of life.

Backscattering cross-section

The ratio of the acoustic power scattered at an angle of 180° from the incident acoustic wave to the acoustic intensity incident on a unit volume or area. This measure, typically referenced to a unit distance, e.g. 1 m, is the ratio of the reflected acoustic power to incident acoustic power per unit area. The units of this ratio are area, e.g. m².

Backshore

That part or zone of a beach profile that extends landward from the sloping foreshore to a point of either vegetation development or a change of physiography, e.g. a sea cliff or a dune field.

Banda Sea

A regional sea in the Australasian Archipelago covering approximately 470,000 square kilometers and centered at about 126° E and 5° S. It consists of several basins and troughs interconnected by sills whose depths are mostly greater than 3000 m.

Bar

A unit of pressure equal to the pressure of 29.530 in. or 750.062 mm of mercury under the standard conditions of 0°C temperature and 9.80665 m/s² gravitational acceleration.

Baroclinic

Descriptive of an atmosphere or ocean in which surfaces of pressure and density intersect at some level or levels. The state of the real atmosphere and ocean, as opposed to barotropic mode. In a baroclinically stratified fluid total potential energy can be converted to kinetic energy.

Barotropic

Descriptive of a hypothetical atmosphere or ocean in which surfaces of pressure (isobaric surfaces) and density (isentropic surfaces) coincide at all levels, as compared to baroclinic. In a state of barotropic stratification, no potential energy is available for conversion to kinetic energy.

Barrier reef

One of three geomorphologically distinct types of coral reefs, the other two being fringing reefs and atolls. Barrier reefs are separated from land by a lagoon usually formed by coastal subsidence.

Barrier layer

In physical oceanography, the layer between the thermocline and the halocline. It is called this because of its effect on the mixed layer heat budget due to the temperature at the bottom of the barrier layer being zero, which excludes heat loss to the underlying water via mixing.

It is defined as the difference between the thickness of the isothermal layer and the mixed layer (determined by a defined change in density), with the isothermal layer generally being greater than or equal to the mixed layer depth. In the Western Pacific, an area with a barrier layer, horizontal temperature gradients are also very small, leading to the conclusion that the net heat flux at the ocean surface must be close to zero.

Basin

A depression of the sea floor more or less equidimensional in form and of variable extent.

Bathyal zone

The marine ecologic zone that lies deeper than the continental shelf but shallower than the deep ocean floor, i.e. those depths corresponding to the locations of the continental slope and rise. The depth range is from 100-300 m down to 1000-4000 m depending on such variables as the depth of the shelf break, the depth of light penetration, and local physical oceanographic conditions.

Bathymetry

The measurement and charting of the spatial variation of the ocean depths.

Bathypelagic zone

One of five vertical ecological zones into which the deep sea is sometimes divided. This is the zone starting from 100 to 700 m deep (coinciding with the upper limit of the psychrosphere) at the 10°C isotherm. The number of species and populations decreases greatly as one proceeds into the bathypelagic zone where there is no light source other than bioluminescence, temperature is uniformly low, and pressures are great. This overlies the abyssopelagic zone and is overlain by the mesopelagic zone.

Bathythermograph

A device developed by Athelstan Spilhaus in 1938 to measure temperature/depth profiles in the ocean, the bathythermograph was basically a reworking of a mostly unworkable device called an oceanograph built in 1934 by Carl-Gustav Rossby for the same purpose. It consisted of an open, rectangular frame in which a compressible bellows with a pen arm and stylus was mounted at one end. The stylus rested on a smoked glass slide and moved across it to scratch a record of ocean temperatures. The stylus also moved vertically with changes in depth and thus created a temperature/depth profile.

The bathythermograph (or BT) was further improved by Maurice Ewing and Allyn Vine in 1940. Their version responded more quickly to temperature changes and was streamlined so it could be lowered and raised more quickly from a moving ship than could the previous more unwieldy version. In 1940 WHOI started doing military research for the government, a large part of which was concerned with sonar and the use of BTs with it. Knowledge of the vertical temperature structure of the ocean was extremely helpful to sonar operators since sound speed in sea water is a strong function of temperature, and various types of vertical temperature profiles would lead to sound traveling differently in the ocean. BT data was also useful for adjusting the buoyancy or trim of submarines since it could help provide an estimate of how much ballast would be needed to move a submarine from periscope depth to greater depths. A strong thermocline would require much more ballast for the submarine to descend.

The military research also led to further improvements in the BT including better aerodynamics for more stable operation at higher speeds as well as moving the glass slide and stylus from within the BT to inside the submarine. By early 1943 many submarines were outfitted with and used BTs. In an extremely helpful quid pro quo, the glass slides were given to WHOI and Scripps after missions in both oceans, allowing charts of the vertical temperature structure of the ocean to be constructed. Over 60,000 slides from the North Atlantic alone were thus made available to oceanographers.

Bay of Bengal

The northeastern arm of the Indian Ocean, located between peninsular India and Burma. It covers about 2,200,000 sq. km and is bordered on the north by the Ganges and Brahmaputra River deltas, on the east by the Burmese peninsula and

the Andaman and Nicobar Islands, on the west by India proper and Ceylon, and on the south by the Indian Ocean proper. The average depth is around 3000 m with maximum depths reaching over 400 m in the southern parts.

Major circulation features are the East Indian Current, a northward current flowing along the Indian shelf from January through October, and the East Indian Winter Jet, a southwestward flowing current that replaces during the remainder of the year. This current reversal is due to the seasonal change from the Northeast to the Southwest Monsoon and the concomitant wind forcing. General clockwise and counterclockwise circulation gyres are seen throughout the Bay accompanying, respectively, the Current and the Winter Jet, although the situation becomes a bit more complicated during the transition periods.

The monsoonal wind variations and the resulting circulations also serve to induce upwelling near the coasts during the spring (with the northward current) and the piling up of surface water along the coasts during the late fall and early winter (with the southward currents). Thus the isopycnals tilt upwards and downwards towards the shore during, respectively, the spring and late fall. The annual mean SST for the region is above 28.5°C., although upwelling can reduce this to 25-27°C during the spring. The salinities are kept lower than normal oceanic values (especially in the western parts) by extensive monsoonal river runoff.

Bay of Bengal Water

A water mass that originates in the northern Bay of Bengal via monsoonal input from the Ganges and Brahmaputra Rivers. It is a low salinity water mass that spreads across the Bay in an approximately 100 m thick layer that produces a strong halocline beneath (above the overlying Indian Central Water) and keeps the surface salinity in the eastern parts of the Bay below 33.0 throughout the year. Although there are no variations in temperature through the BBW layer, there are salinity variations below 50 m (and therefore above the main halocline) due to the fact that weak wind mixing erases variations over only about half the depth of the layer. This causes the permanent existence of a barrier layer. The low salinity surface water to the west of India, sometimes called East Arabian Sea Water (EAW), is usually subsumed under the BBW rubric due to its nearly identical properties.

Beach

Unconsolidated sandy or sediment area extending from low tide mark to the landward side where physiographic vegetation exists.

Berm

The nearly horizontal portion of a beach formed by the deposition of sediment by receding waves. A beach may have more than one berm.

Berm crest

The seaward limit of a berm on the beach.

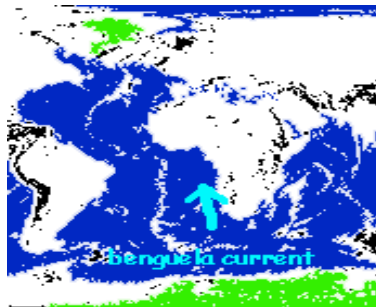
Beach face

The sloping section of a beach profile below the berm which is normally exposed to the action of the swash.

Benguela Current

A current that flows northward along the west coast of southern Africa between about 15 and 35° S. This is the eastern limb of the subtropical gyre circulation system in the South Atlantic Ocean.

The icy Benguela current moves north from the Southern Ocean (around Antarctica) and flows northwards along the West Coast of Africa. Along with the accompanying winds the Benguela current reaches as far as southern Angola, making it extremely difficult to travel southward along the Atlantic Coast. Where the icy Benguela meets the warm, south- and west-flowing Agulhas, there is a rich sea life beneath the surface, but tremendous turbulence above. South African folklore considers the meeting of the two currents-the cold Benguela and the warm Agulhas (roughly off the Cape of Good Hope) as the place where the two oceans meet.



Benthic

Descriptive of organisms that are attached to or resting on bottom sediments, as opposed to pelagic.

Benthos

One of three major ecological groups into which marine organisms are divided, the other two being the nekton and the plankton. The benthos are organisms and communities found on or near the seabed. This includes those animals (zoobenthos) and plants (phytobenthos) living on (epifauna) or in (endofauna) marine substrata as well as those that swim in close proximity to the bottom without ever really leaving it. In terms of size, this is generally divided into three categories: meiobenthos, the organisms that pass through a 0.5 mm sieve; macrobenthos, those that are caught by grabs or dredges but retained on the 0.5 mm sieve; and epibenthos, those organisms that live on rather than in the seabed. Those in the latter category are usually larger.

Benthic life is subject to vertical zonation depending chiefly on light, moisture and pressure. This has led to the division of benthonic animals into two systems and seven zones. Proceeding from shallow to deep water, the first system is the

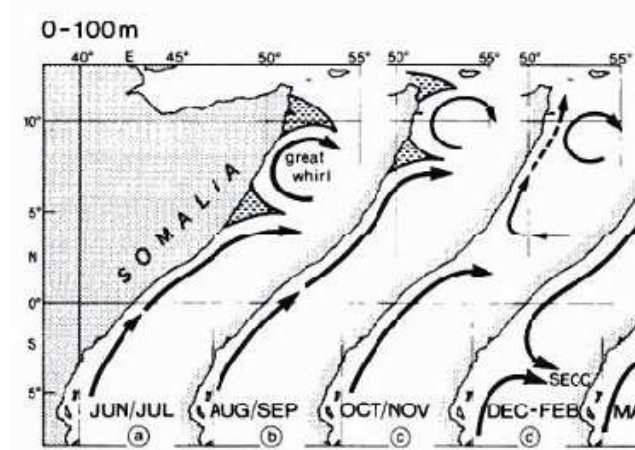
phytal or littoral system, composed of the supralittoral, mediolittoral, infralittoral and circalittoral zones. The second system, the aphytal or deep system, is composed of the bathyal, abyssal and hadal zones.

BIW

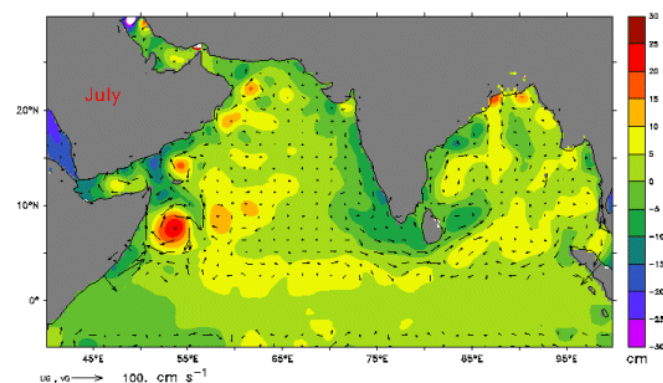
Abbreviation for Banda Intermediate Water.

Big or great whirl

With the onset of intense southwest monsoon winds in June, a strong anticyclonic gyre forms, called the 'Great Whirl' that develops in the north between 4°N and 10°N. A third Gyre, the 'Socotra Eddy' is also observed in summer monsoon northeast of Socotra. In August-September, the southern cold wedge propagates northward along the coast and meets the northern one and the Somali Current appears as a continuous current from the equator up to 10°N.



The big whirl or Great whirl in the Somali current



Boreal period

A post-LGM European climate regime. This refers to the period from about 7000-6000 BC when temperatures continued to rise, e.g. the colder seasons of the year

gradually became milder (although probably with some dry and frosty winters) and the summers became generally warmer than today. It was preceded by the Pre-Boreal Period and followed by the Atlantic period.

However, at present the usage Boreal winter or summer means Northern hemisphere winter or summer.

Bowen's ratio

The ratio of the amount of sensible to that of latent heat lost by a surface to the atmosphere by the processes of conduction and turbulence.

Caballing or cabbeling

In physical oceanography, a phenomenon that occurs when two water masses with identical densities but different temperatures and salinities mix to form a third water mass with a greater density than either of its constituents. This is hypothesized to be a major cause of sinking in high northern latitudes.

Calcareous ooze

A fine-grained, deep-sea deposit of pelagic origin containing more than 30% calcium carbonate derived from the skeletal material of various plankton. It is the most extensive deposit on the ocean floor but restricted to depths less than about 3500 m due to the carbon compensation depth

Challenger Expedition (1872-1876)

A three and a half year voyage starting in 1872 that laid the scientific foundation for every major branch of oceanography. The ship, captained by George S. Nares and later Frank T. Thomson, took over 350 stations in all the oceans except the Arctic and logged 68,890 nautical miles. Perhaps the only ultimately unsatisfying aspect of the expedition was that the ship, a spar-decked vessel with auxiliary steam power, was slow and clumsy and had the habit of rolling about 50° to either side. The expedition was led by Sir Wyville Thompson, with his chief assistant John Murray and the expedition's chemist J.Y. Buchanan also playing major roles.



The observations and records obtained aboard the *Challenger* furnished data for charting the main bathymetric contours of the ocean basins, established the cold and relatively constant nature of temperatures at great depths, located the exact position of many islands and sea mounts, established that there was no zone in the sea in which life did not exist, and enabled the construction of accurate charts of the principle surface (and some subsurface) currents in the world ocean. The deep

sea data were obtained with trawls lowered on hemp ropes. The ship dragged for samples in water as deep as 4,475 fathoms and trailed as much as eight miles of line in trawls that took 12 or 14 hours to complete.

The foundations of marine geology were laid by Murray with his study of the deep-sea sediments obtained in the trawls. The sediments discovered were newly classified as globigerina, radiolarian or diatom oozes or red clay, and their spatial distribution was mapped. The plankton nets, simple bags of muslin or silk attached to iron rings one foot in diameter captured many new planktonic forms, permanently changing that branch of marine biology. Many new and different forms of life were dredged from great depths, permanently dispelling the notion that these depths were lifeless and founding deep-sea biology. The expedition's chemist Buchanan took seventy-seven water samples throughout the oceans, deriving data from these that formed the foundation of chemical oceanography. He also dispelled the myth of *Bathybius*.

The scientific results of the expedition were published in fifty large volumes over fifteen years, edited first under the direction of Thompson and, after his death, by Murray. The best artists in England were hired to create the illustrations. The funding for this publishing endeavor was not included as part of the budget of the expedition and it was a constant struggle for Thompson and Murray to obtain financial resources to complete the endeavor, so it might also be said that the foundations for the difficulty of obtaining funds for oceanographic research were also laid by this expedition.

The *Challenger* Expedition probably contributed more to the science of oceanography than any single expedition before or after. It marked the beginning of oceanography as a disciplined science, with the scientists establishing a pattern of scrupulously precise observations and efficiency. While the quality of ships and of sampling and measuring devices have greatly improved since 1872, it is doubtful that the standards set by the *Challenger* Expedition will ever be exceeded. It was truly a landmark in oceanography.

Canyon

A relatively narrow, deep depression with steep slopes, the bottom of which grades continuously downward. Canyons are common on shelves, often extending across the shelf and down the continental slope to deep water.

Centiliter per ton (Cl/t)

It is a unit to represent the specific volume or thermosteric anomaly of sea water. $1\text{cm}^3\text{g}^{-1} = 10^{-3}\text{litreg}^{-1} = 10^5\text{Cl/t}$. The range of thermosteric anomaly in sea water may be of the order of 50 to 100 Cl/t.

Chlorinity

A concept originally defined (circa 1900) to circumvent the difficulties inherent in attempting to directly measure the salinity of sea water. It was determined by volumetric titration using silver nitrate and originally defined as "the weight in grams (in vacuo) of the chlorides contained in one gram of seawater (likewise measured in vacuo) when all the bromides and iodides have been replaced by chlorides." This was defined in terms of the atomic weights known in 1902 and as such was dependent on any changes in their determinations. The weights did change so the definition was kept in terms of the 1902 atomic weights until a new definition was determined in 1937. The new definition of chlorinity as "the mass of silver required to precipitate completely the halogens in 0.3285234 kg of sample seawater" was free of this limitation.

The chlorinity was later defined in terms of electrical conductivity when it was determined that density may be predicted from conductivity measurements with nearly an order of magnitude better precision than from a chlorinity titration. This change was also predicated on the development of precise and reliable electronic instruments in the 1950s to perform the measurements. This led to the present method of calculating the chlorinity (and thence salinity) by experimental determination of a relationship between chlorinity and the conductivity ratio of a sample at atmospheric pressure and 15°C to that of a standard seawater.

Chlorosity

The number of grams of chloride and chloride equivalent to the bromide in one liter of sea water at 20°C.

It is defined as the total amount of chlorine in grams present in one liter of sea water when bromine and iodine are replaced by an equivalent amount of chlorine.

Chlorosity = chlorinity × density

Circumpolar Deep Water (CDW)

The most extensive water mass found in the ACC, CDW is usually further split into Upper Circumpolar Deep Water (UCDW) and Lower Circumpolar Deep Water (LCDW). UCDW is characterized by an oxygen minimum and nutrient maxima (with sources in the Indian and Pacific Oceans) as well as by a relative minimum in temperature south of the Subantarctic Front (SAF) induced by the overlying Antarctic Intermediate Water (AAIW) and Winter Water. LCDW is characterized by a salinity maximum and nutrient minima derived from North Atlantic Deep Water (NADW).

The source region of the split (and LCDW) is in the southwest Atlantic where relatively warm, salty, oxygen rich and nutrient poor NADW meets the ACC just below the oxygen minimum therein, thus splitting the CDW into two parts. The upper branch of this split retains the oxygen minimum layer present before the split, with the lower branch also showing an oxygen minimum induced by high oxygen concentrations in both the overlying NADW and the underlying Antarctic Bottom Water. The latter minimum has been eroded via mixing by the time the LCDW reaches the Greenwich Meridian, to be replaced by a general increase in oxygen from the UCDW minimum to the bottom.

The oxygen minimum of the UCDW lies slightly below the phosphate and nitrate maxima. At the Drake Passage the concentrations in this minimum increase from 3.7 mL/L in the Subantarctic Zone (SAZ) to 4.1 mL/L in the Antarctic Zone (AZ). The NADW influx to the east of this reverses this trend such that concentrations decrease to the south at the Greenwich Meridian, e.g. from 4.2 mL/L near the SAF to less than 4.1 mL/L near the PF. The mean concentrations of the nutrient maxima at the Drake Passage are 2.42 $\mu\text{mol/L}$ for phosphate and 35.4 $\mu\text{mol/L}$ for nitrate. The phosphate maximum is eroded by NADW north of the PF such that it is reduced to 2.36 $\mu\text{mol/L}$ at the Greenwich Meridian, although it is unchanged south of the PF. The nitrate concentration erodes slightly to 34.8 $\mu\text{mol/L}$ north of the SAF at the Greenwich Meridian, while it increases to as high as 36.8 $\mu\text{mol/L}$ near the PF.

The mean salinity at the LCDW salinity maximum at Drake Passage is 34.729, the lowest in the Southern Ocean since there it is most remote from the NADW source of the maximum. The phosphate minima concentration at Drake passage is about 2.25 $\mu\text{mol/L}$ while the nitrate minima is 32.5 $\mu\text{mol/L}$. That are reduced to, respectively, 1.98 $\mu\text{mol/L}$ and 29.9 $\mu\text{mol/L}$, north of the PF at the Greenwich Meridian, with the concentrations reduced even south of the PF, although to a lesser degree.

In the Atlantic, LCDW is found in all basins. From the Argentine Basin it flows north and invades the Brazil Basin via the Vema and Hunter Channels and the Lower Santos Plateau. At the northern end of the Brazil Basin, the flow splits into an eastward branch through the Romanche Fracture Zone and a northwestward one, which spills over the broad equatorial sill into the Guiana Basin and finally into the North American Basin, where it can be identified up to 40°N. The eastern North Atlantic, that is, the Cape Verde, Canary and Iberian Basins, are supplied via the Vema Fracture Zone at ≈11°N. Here LCDW influence has been traced northward up to ≈32°N. The Sierra Leone and Angola Basins get their LCDW contribution through the Romanche Fracture Zone from the Brazil Basin; however, the abyss of the southwesternmost corner of Angola Basin is also partly influenced by LCDW, which originates from the Cape-Agulhas Basin and spills over deep sills in the Walvis Ridge named the Walvis Passage.

Continental slope

It is the declivity seaward from the shelf edge into greater depth. The relatively steep slope usually found between the continental shelf and the abyssal plain. Continental slopes range from 3 to 6° in slope (with 4° being about average), range in depth from 100-300 m to 1400-3200 m, range in width from 20-100 km, and occupy about 8.5% of the ocean floor if the 2000 m contour is taken as the

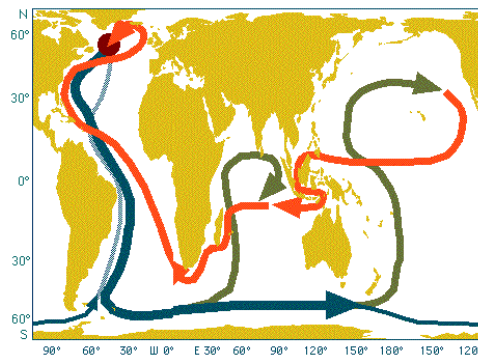
deeper border. The continental shelf and slope are said to comprise the continental margin.

Continental (or Island) Shelf

A zone adjacent to a continent (or around an island) and extending from the low-water line to the depth at which there is usually a marked increase of slope to greater depth.

Conveyor belt

A simple model of a closed global thermohaline interbasin exchange circulation scheme introduced by Broecker (1987 and 1991), and Gordon (1986). Cold and salty deep water formed in the Norwegian or Greenland Sea (called NADW) flows southward as a deep current where around 30% is transported via the ACC to the Indian and Pacific Oceans. The flow travels northward along the western boundaries of these oceans and upwells in the northern portions. This drives a warm, shallow return flow that travels from the Northern Pacific through the Indonesian Archipelago and the Indian Ocean (gaining the water upwelled there) towards the South Atlantic via the southern tip of Africa. There it is joined by the remaining 70% that mixed with AAIW and returned to the North Atlantic via the Drake Passage. A general northward flow returns the water to the North Atlantic. The regions of deep water formation around Antarctica form AADW which flows under and mixes with the NADW, forming another component in the mixture. This is a simple (and to some an overly simplistic) view of the thermohaline circulation, but it is useful as a first order description. A more complete and accurate version of the interbasin exchange circulation pattern has been developed.



The path of North Atlantic Deep Water through the world ocean (The "Great Ocean Conveyor Belt"). Blue indicates deep currents, olive intermediate currents (about 1000 m depth) and orange surface currents.

Water sinks to the ocean floor in the North Atlantic Ocean (the brown circle). It moves southward as North Atlantic Deep Water and joins the Circumpolar Current. Some of it returns to the North Atlantic Ocean as a deep current, the remainder rises to intermediate depth, moves north across the equator, rises further into the upper ocean and returns to the North Atlantic Ocean with the surface currents

CTD:

Temperature readings and water samples are usually taken together. Most water sampling from research vessels now utilizes modern electronic instruments

known as CTD (conductivity-temperature-depth) probes developed in the 1970s. These are usually mounted on rosette water samplers. Temperature is measured through electrical resistance with an accuracy greater than that of mercury thermometers (0.0028°C). Development of electrical resistance thermometers was made possible with the advent of the transistor and integrated circuit and such thermometers were first used in the early 1960s, although at this time they were not very accurate. Salinity, to an accuracy of 0.005 units, is calculated from measurements of the electrical conductivity and temperature of the water using a *salinometer*. The data return to the ship as an electronic signal and are interpreted by on-board computers or connected to graphic or digital display units. However, the conductivity measurements need to be calibrated against water samples which is why CTDs are usually used as part of an instrument package which includes a water sampler. Rosette multisamplers can have as many as 24 bottles of 2, 10 or even 20 litre capacity which collect water at the required depths, when triggered electronically from the surface. Water samples are also necessary for chemical analysis of water. Small, hand-held salinometers on long cables are also available for use in shallow water from small boats.

CTDs can be lowered from stationary ships to provide continuous data from the surface down to about 6000 m. They can also be left in place if attached to a fixed buoy, to record changes in salinity and temperature over time. The data can be stored in the instrument or transmitted to a base via a satellite. Fluorometers (chlorophyll content) and oxygen electrodes are also routinely attached to the instrument package. Oceanographic work requires extremely accurate thermometers because small variations in temperature produce considerable changes in water density. Modern CTD instruments have greatly increased the precision, speed and accuracy of measurements. As already mentioned, water samples are still needed to calibrate salinity measurements from these instruments. Precision thermometers are also used to check the accuracy of the CTD instruments. These usually have platinum resistance sensors and an LCD display rather than mercury in glass.

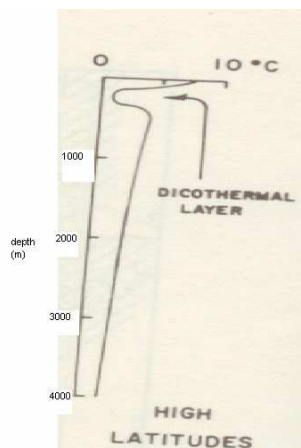


Cyclonic

The direction of rotation around a center of low pressure. This is counter-clockwise in the northern hemisphere and clockwise in the southern. The term originates from the circulation observed around tropical cyclones.

Dicothermal layer

A vertical ocean layer sometimes found in high northern latitudes. It is a cold (as low as -1.6°C) layer from 50 to 100 m sandwiched between warmer surface and deeper layers. The water column remains stable due to a salinity gradient that counters the unstabilizing effects of the temperature gradient.



Diurnal

Generally occurring once a day. Description of a tide that has only one high and one low water per day occurring in a coast. Also used in describing temperature variation of a locality as occurring one peak and low in a day.

Dynamic height

Dynamic height, **D**, is the integral of the specific volume over pressure. It is expressed in units called dynamic meters, which actually has dimensions of work per unit mass, or m^2s^{-2} . With this choice of units, the difference in dynamic height between points 1 m apart in the vertical is approximately 1 dynamic meter.

In oceanography, this refers to the pressure associated with a column of water. Horizontal variations of this (due to horizontal variations in temperature and salinity) are mapped to determine what is called the dynamic topography and its corresponding geostrophic flow field in the ocean. The dynamic height is measured in dynamic meters and is defined by

$$D(p_1, p_2) = \int_{p_1}^{p_2} \delta(T, S, p) dp$$

where p_1 and p_2 are two reference pressure levels, δ the specific volume anomaly, T the temperature, S the salinity, and p the pressure. This is analogous to a meteorologist's use of a pressure chart, with the direction of flow aligned with the contours and the intensity of flow inversely proportional to the contour spacing. Dynamic heights are preferred over geometric heights in oceanography and meteorology because energy is generally lost or gained when a parcel of fluid moves along a surface of equal geometric height but not when it moves along a surface of equal dynamic height. This quantity has also been called dynamic thickness, dynamic distance, geopotential height, geopotential thickness, and geopotential distance.

Dynamic meter

In oceanography, a unit of gravity potential used to express the amount of work that is performed or gained in moving a unit mass from one level to another. A dynamic meter represents the work performed in lifting a unit mass nearly 1 m and is defined as 10^5 dyn-cm/gm or 10 J/kg. The depth in dynamic meters is

related to the depth in geometric meters via $D = gh/10$, where g is the gravitational acceleration and h the geometric depth, i.e. 1 dynamic meter corresponds roughly to 1.02 geometric meters. This is used instead of the geometric meter since gravity is the most important of the acting forces and as such a coordinate system based on gravity is advantageous.

Dynamic topography

In oceanography, a field of horizontally varying dynamic heights in the ocean, analogous to, for example, a topography field on land. This is also called geopotential topography.

East Arabian Current

A strong northeastward flowing current along the Saudi Arabian coast. It is part of the monsoonal circulation in the area and as such exists from about April through October, being fully established by mid-May with velocities ranging from 0.5-0.8 m/s. It is also part of a strong coastal upwelling system during those months when it flows strongest.

East India Coastal Current

A seasonal and northward flowing current found in the western part of the Bay of Bengal along east coast of India from about January until October. The weak and variable currents found early in the year strengthen with the Northeast Monsoon, exceeding 0.5 m/s by March and ranging from 0.7-1.0 m/s through May and June. This current flows counter to the wind, apparently as an extension of the North Equatorial Current, although a convincing dynamical explanation has yet to be offered. The northward flow gradually weakens with the advent of the Southwest Monsoon, with the currents to the north and close to the shelf beginning to reverse

in September. By late October, the East India Coastal Current has completely reversed into the East Indian Winter Jet.

East Indian Winter Jet

A seasonal southwestward flowing western boundary current found in the western Bay of Bengal from late October through around late December. It features velocities consistently above 1 m/s as it flows southwestward, eventually turning west and following topographic contours as it passes Sri Lanka and feeds all its waters into the Arabian Sea. In late December its northern part fades, eventually to become the East Indian Current, and the southern part merges with the developing North Equatorial Current..

Echo sounder

An instrument used to determine ocean depth by measuring the time needed for a sound wave to travel from the ship to the ocean floor and return. The first reliable acoustical sounding machine was built by A. Behm in 1919, who called it an echo sounder. An echo sounder consists of three main components: the sound transmitter, the sound receiver, and a device to measure time.

Eddy conductivity

The exchange coefficient for the transfer of heat by eddies in turbulent flow, i.e. eddy heat flux. This is also called the eddy conduction coefficient.

Eddy viscosity

A coefficient used to achieve closure in the Reynolds equations for turbulent flow. The assumption is made that the Reynolds stresses are related to the velocity gradients of the flow by a viscosity analogous to the molecular viscosity, i.e. a turbulent or eddy viscosity. The utility of the analogy is strained by the fact that while the molecular viscosity is a property of the fluid, the eddy viscosity is a property of the flow. As such the specification of the eddy viscosity has more than a little of the air of the ad hoc about it since it is usually found via a trial-and-error procedure wherein it is varied until a numerically simulated flow reasonably replicates a known flow. The value thus obtained diagnostically is then used for prognostic simulations, a procedure that is questionable due to the abovementioned fact of the eddy viscosity being a property of the flow rather than the fluid. That is, if the flow is remarkably different, then the eddy viscosity may also be remarkably different.

In the ocean eddy viscosity values range typically from 10 to 10^5 m²/s in the horizontal and from 10^{-5} to 10^{-1} m²/s in the vertical, with both values more often found towards the higher ends of their ranges.

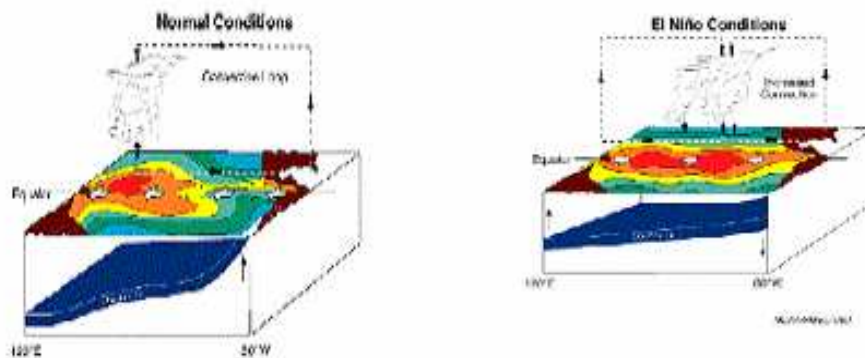
Ekman pumping

In oceanography, a process that is the result of a combination of Ekman dynamics and horizontal variations in the wind stress. The resulting convergence and divergence of the surface flow will force vertical water motion called Ekman pumping or suction, respectively.

El Niño

A term originally applied as a description of an annual weak warm current running southward along the coast of Peru and Ecuador during the Christmas holiday, i.e. the Spanish word for "the boy Christ-child" is Niño. The name El Niño eventually became associated with unusually large warmings that occur every few years and effect large changes on the local, regional, and even global climate. It gradually became known that the coastal warming was part of a much larger warming of the upper waters of the Pacific extending as far as the International Date Line. There is an associated atmospheric phenomenon called the Southern Oscillation, with the combined changes in atmosphere and ocean termed El Niño/Southern Oscillation or ENSO, with El Niño properly referring the warm phase of ENSO. A typical El Niño event begins in the northern spring or sometimes summer, peaks from November to January in SSTs, and ends the following summer. The opposite phase is similarly called La Niña, i.e. Spanish for "the girl," and features a basin wide cooling in the tropical Pacific. The entire system is called El Niño in many if not most popular accounts.

More quantitative definitions have been proposed for classification purposes. Although none is recognized as official, several objective methods have proved useful. Most involve calculating the deviation from average of temperatures in rectangular regions in the tropical Pacific, with the averaging period, baseline temperatures, qualifying deviation, and specific region varying from definition to definition. The defined averaging regions include: Niño 3 (5°N - 5°S , 90° - 150°W); Niño 3.4 (5°N - 5°S , 120° - 170°W); and Niño 3.5 (5°N - 10°S , 120° - 180°W). A typical calculation would find periods during which 5 month running means of monthly SST anomalies in a given area are $+0.4^{\circ}\text{C}$ or more for at least six consecutive months. Applying this particular procedure to Niño 3.4 picks out most historically prominent El Niño events.



ENSO in the Indian Ocean

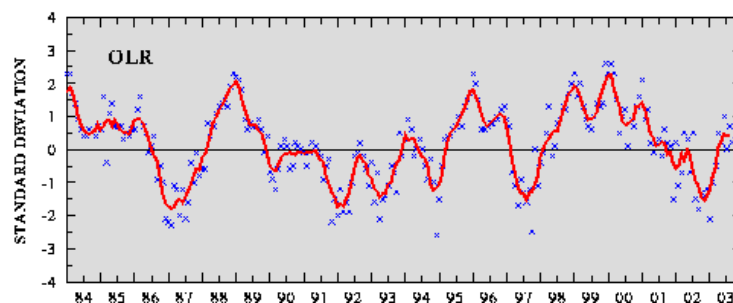
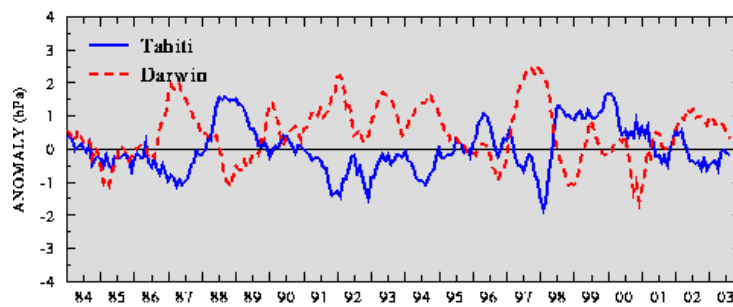
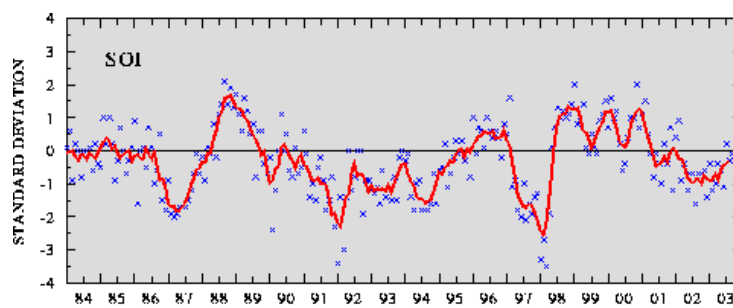
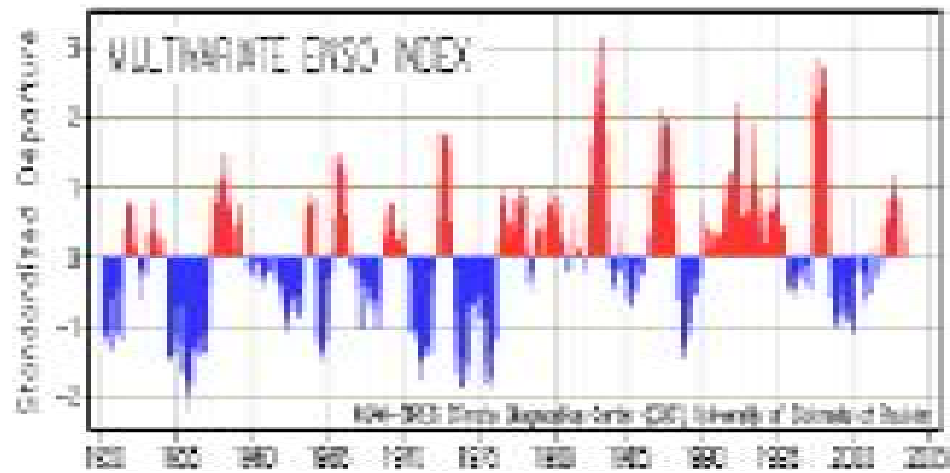
Toure and White in 1994 has found that the Indian Ocean like the Pacific Ocean has an El Niño signal. As part of this event a warm pool in the Indian Ocean moves eastward in a cycle of 3 to 7 years. The same phenomenon occurs in the Pacific. Their research will enable better forecasting of climate changes that cause droughts and floods in the Indo-Pacific region, and in the equatorial Atlantic, where a warm pool develops 12-18 months after the El Niño in the Pacific and Indian Oceans.

The research for the first time links the two oceans in a related pattern occurring over 3 to 7 years, whose effects on the world's climate could be more far-reaching than previously thought. The discovery of a more global aspect to the El Niño/Southern Oscillation (ENSO) could advance scientists' understanding of the Pacific El Niño, improving their ability to forecast El Niño-spawned droughts, floods and storms all over the world.

The atmosphere over the North Indian Ocean undergoes strong interannual variability which appears to be related to both the strength of the South Asian monsoon (southwest monsoon) and the El Niño-Southern Oscillation (ENSO). It is also shown that there is substantial variability in ocean dynamical and thermodynamical structures, commensurate with the atmospheric forcing. The relationship between the observed variability and the strength and characteristics of the Asian monsoon is explained in the context of sea-surface temperature (SST) - monsoon strength connections in both the Indian and Pacific oceans. In particular, two of the years analyzed (1987 and 1988) illustrate the ability of the Indian Ocean to undergo substantial variability in meridional heat transport and oceanic heat storage (in response to large variations in the surface radiative fluxes and wind stresses), while maintaining SST's within a fairly constant range.

The western Pacific Ocean and the northern Indian Ocean possess the warmest SST's on the globe, constituting the tropical ocean warm pools. However, their surface heat budgets are entirely different. The net heat flux into the northern Indian Ocean is between 75-100 Wm^2 during the boreal spring and early summer but only 10-20 Wm^2 in the western Pacific during the entire year. The differences in surface heat fluxes arise from the radiation shielding of the deep convective clouds over the western Pacific and the near absence of clouds over the northern Indian Ocean during spring. Yet, with the different inputs of heat into the two regions, the SST variations between them are very small: both stay within rather narrow confines between 26-30°C.

Despite the strong heat flux during the northern spring and early summer, the northern Indian Ocean only warms by 3° C over a four month period, much smaller than the 9°C expected from theoretical considerations. The cloudy western Pacific Ocean, on the other hand, varies throughout the year by $\pm 1^\circ\text{C}$. Furthermore, for the spring and early summer there is a fairly strong negative correlation between outgoing long wave radiation (OLR) in the Pacific Ocean but almost no correlation in the Indian Ocean. It is argued that regulation in the Pacific Ocean is a combination of local thermo-dynamical balance and changes in the large-scale atmospheric circulation. In the Indian Ocean, SST is regulated by strong advection of heat southward across the equator and by changes in heat storage.



Epipelagic zone

One of five vertical ecological zones into which the deep sea is sometimes divided. The epipelagic zone extends from the surface downward as far as

sunlight penetrates during the day. It is a very thin layer, less than 100 meters thick in the eastern parts of the oceans in regions of upwelling and high productivity and up to 200 meters thick in clear subtropical areas. The endemic species of this zone either do not migrate or perform only limited vertical migrations, although there are many animals that do invade the epipelagic zone from deeper layers during the night or pass their early development stages in the photic zone. The epipelagic zone overlies the mesopelagic zone.

Equatorial Countercurrent

In physical oceanography, a subsurface eastward flow that is about 100-200 m thick and 200-300 km wide. It is centered approximately on the equator, and its core lies just beneath the base of the mixed layer in the top of the equatorial thermocline. Such a current is found in all three oceans, although it appears to be a seasonal phenomenon in the Indian Ocean.

Equatorial Undercurrent

In physical oceanography, a subsurface eastward flow centered approximately on the equator whose core lies just beneath the base of the mixed layer in the top of the equatorial thermocline. The flow generally ranges from 100-200 m thick and 200-300 km wide. Such a current is found in all three oceans, although it appears to be a seasonal phenomenon in the Indian Ocean. In the Atlantic its core is around 100 m deep with speeds exceeding 1.2 m/s and transports up to 15 Sv. It alternates between extreme positions 90 km on either side of the Equator on a 2-3 week time scale with speed and transport fluctuating between the previous figures and 0.6 m/s and 4 Sv. In the Pacific it has a width of 400 km, a thickness of only 200 m, and typical velocities of 1.5 m/s, with the core depth ranging from 200m in the west to 40 m in the east. The details are much more complicated and less well known for the Indian Ocean, although it appears to be present primarily during the northeast monsoon. This is also known as the Cromwell Current in the Pacific Ocean after Cromwell et al. (1954).

The dynamical explanation for an undercurrent has an appealing qualitative explanation, i.e. fluid converging towards the equator conserves absolute vorticity. As a result, relative vorticity has to increase to make up for the vanishing of planetary vorticity there, with this providing a source of eastward momentum to drive the undercurrent. The balance of forces at the equator reduces to

$$\frac{\partial p}{\partial x} = \frac{\partial}{\partial z} \left(\nu \frac{\partial u}{\partial z} \right)$$

where p is the pressure (baroclinic), x the coordinate along the equator, ν the momentum diffusion coefficient, z the vertical coordinate, and u the along equator velocity component. This is a linear equation, and although the addition of nonlinearities has brought model results and observations into closer concordance, it is thought that they are not essential for maintaining the undercurrent and serve only to modify the linear dynamics. The unsteady flow represented by the

dynamics of equatorial waves has also been postulated as an explanation for the observed time-varying characteristics of the undercurrent.

Equatorially trapped Kelvin wave

An equatorially trapped wave similar in character to coastally trapped Kelvin waves. The motion is unidirectional and parallel to the equator everywhere, and in each vertical plane parallel to the equator the motion is the same as for a nonrotating fluid. A required geostrophic balance between the east-west velocity and the north-south pressure gradient leads to solutions that decay away from either side of the equator on a length scale called the equatorial radius of deformation. These dispersionless waves propagate eastward at the same speed as they would in a nonrotating fluid, with the dispersion relation being $\omega = ck$. The magnitude of c for the first baroclinic mode for typical ocean values is around 2.8 m/s, which would take a Kelvin wave across the Pacific in about 2 months.

Equatorially trapped wave

A wave that is confined to propagate on and near the equator due to the local waveguide properties. The waveguide is caused by the vanishing of f_0 at the equator. This means that the conditions for geostrophic balance theoretically fail there, although practically any wave motion having a finite expanse across the equator will feel the Coriolis force on either side. This will serve to turn that motion back towards the equator on either side, thus serving as a trap or a waveguide for motions there.

Estuary

A semi-enclosed coastal body of water having a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage. The term has traditionally been applied to the lower reaches of rivers into which sea water intrudes and mixes with fresh water as well as to bays, inlets, gulfs and sounds into which several rivers might empty and in which the mixing of fresh and salt water occurs.

Distinctions between estuaries are usually made based on the prevailing physical oceanographic conditions (principally the salinity distribution) which are governed by the geometry of the estuary, the magnitude of fresh water flow into the estuary, and the magnitude and extent of the tidal motion. The four principal categories into which estuaries are divided using these criteria are well mixed, stratified, arrested salt wedge and fjord entrainment estuaries, although a single estuary can vary seasonally from one type to another.

Euphotic zone

In the ocean, the sunlit layer consisting of the upper 100 m or so in which most of the primary productivity takes place. The depth varies geographically and seasonally and can range from a few meters in turbid waters near the shore to 120 m. It is a zone with sharp gradients in illumination, temperature and salinity, and is the upper of three vertical zones that comprise the pelagic part of the ocean, the other two being the middle mesopelagic and the lower bathypelagic zones. It is also known as the photic zone.

Eustatic

Descriptive of global sea level variations due to absolute changes in the quantity of seawater, the most recent significant examples of which have been caused by the waxing and waning of continental ice sheets during glaciation cycles.

Eutrophic

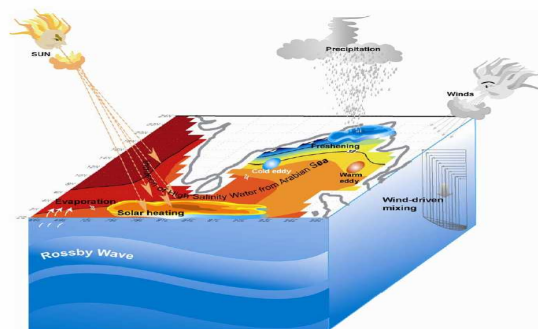
A situation in which the increased availability of nutrients such as nitrate and phosphate (e.g. from the use of agricultural fertilizers and the combustion of fossil fuels) stimulates the growth of plants such that the oxygen content is depleted and carbon sequestered. It is hypothesized that this might serve as a negative feedback to an increase in atmospheric CO₂.

Extinction coefficient

In other words the rate at which the downward travelling light in the oceans decreases is called extinction. A coefficient measuring the rate of extinction, or diminution, with distance of transmitted light in sea water is called extinction coefficient. It is the attenuation coefficient for visible radiation.

$I_O = I_L e^{-kL}$ where k is the extinction coefficient, I_O incident sun light at sea surface, I_L amount of sun light reaching at L meters depth.

Factors effecting MLD:

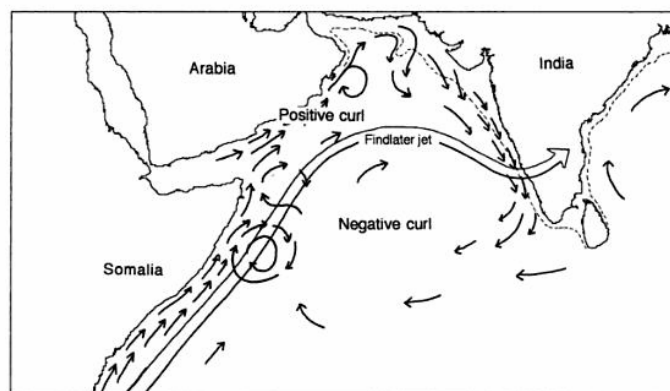


The local forcing that affect the MLD are the precipitation and river runoff, solar heating, wind mixing and meso scale eddies. The remote forcings are the intrusion of high salinity waters from the Arabian sea and propagation of Rossby waves. The figure shows the schematic representation of local and remote forcing that influence the depth of the Mixed layer. Color shading indicates the climatological monthly mean salinity in August. Cold core eddy in blue and warm core eddy in red is shown.

Findlater Jet

Some air from the southern hemisphere enters monsoon weather systems over India and adjacent seas. This air crosses the equator in a low-level jet stream between the meridians of 38° and 55°E . Within this jet stream, wind speeds tend to be highest (upto 50 ms^{-1}) at altitudes of 600 to 2500m. This jet stream is called the Findlater jet stream named after the meteorologist, Findlater, who invented it. The strength of the Findlater jet stream is modulated by extratropical weather systems of south and south east of Madagascar. It appears that the increase in the strength of Findlater jet increases the monsoonal rainfall in west coast of India.

The atmospheric equivalent of an oceanic western boundary current. An example originates with the southwest monsoon that, fed partly from a northward extension of the easterly trade winds over the southern Indian ocean, develops in May. It turns northward and crosses the Equator in the vicinity of the African coast, confined by the highlands of Kenya and Ethiopia. This causes the winds to assume the familiar jet-like structure seen in western boundary currents in the oceans. During the southwest monsoon, a low-level atmospheric feature called the Findlater Jet forms over the ocean, near the coasts of Somalia, Yemen, and Oman. The northeastward flow of the surface current induced by the Findlater Jet causes strong upwelling near the coast, inducing a period of high productivity that is easily observable in composite images of the Arabian Sea for these months.



Fjord & fjord entrainment estuary

One of the four principal types of estuaries as distinguished by prevailing flow conditions. This type features relatively stagnant, deep water mass overlain by a thin river runoff flow, e.g. prevailing summer conditions for the Norwegian fjords.

Foraminifera

An order of Sarcodina, the members of which have numerous fine anastomosing pseudopodia and a shell which is calcareous; the shells of these organisms, when deposited in ocean sediments, are the source of climatic information about ancient temperatures.

Foreshore

The sloping portion of a beach profile that lies between a berm crest (or, in its absence, the upper limit of wave swash at high tide) and the low water mark of the backrush of the wave swash at low tide. This term has been used synonymously with beach face, although the foreshore can also contain some of the flat portion of the profile below the beach face.

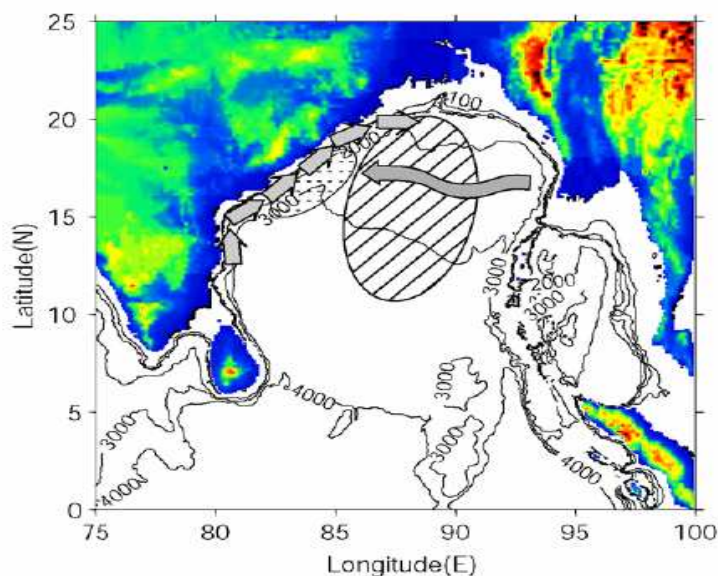
Fringing reef

One of three main geomorphological types of coral reefs, the other two being barrier reefs and atolls. These are formed close to shore on rocky coastlines by the growth of corals and associated hydrozoans, alcyonarians and calcareous algae. Fragments of limestone derived from such bioherms are welded together by the encrusting calcareous algae as well as by the deposition of interstitial calcium carbonate cement, the latter brought about by geochemical reactions and possibly bacterial action. The zone of living corals is separated from the shore by a shallow reef flat where reduced circulation, periods of tidal emersion, and the accumulation of sediments inhibit coral growth.

GARP

Acronym for the Global Atmospheric Research Program, planned and coordinated jointly starting in 1968 by the WMO and the ICSU.

Generation of eddy



The generation of eddy is due to wind stress curl and Rossby waves. The figure shows the mechanism of generation of northern coastal eddy in Bay of Bengal. Smaller ellipse filled with dots and the bigger ellipse filled with slanting lines represents the positive and negative wind stress curl respectively. The small

arrows along the western boundary represent the Western Boundary Current and the large zonal westward arrow indicates the Rossby wave. Labeled contours indicate the bathymetry in meters.

Geodesy

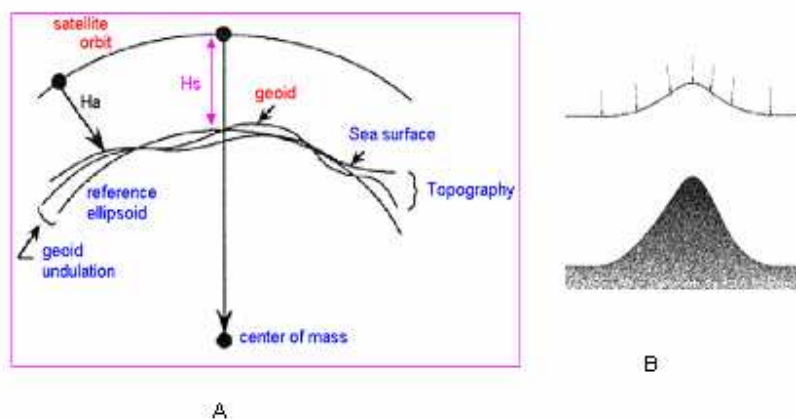
The science concerned with the study of the shape and size of the earth in the geometrical sense and with the study of certain physical phenomena, such as gravity, in seeking explanation of fine irregularities in the earth's shape, and as such in inextricably linked with surveying and cartography.

Geoid

A hypothetical, global, and continuous sea-level surface perpendicular to the direction of gravity at all points.

The level surface corresponding to the surface of an ocean at rest is a special surface, the *geoid*. To a first approximation, the geoid is an ellipsoid that corresponds to the surface of a rotating, homogeneous fluid in solid-body rotation, which means that the fluid has no internal flow. To a second approximation, the geoid differs from the ellipsoid because of local variations in gravity. The deviations are called *geoid undulations*. The maximum amplitude of the undulations is roughly ± 60 m. To a third approximation, the geoid deviates from the sea surface because the ocean is not at rest. The deviation of sea level from the geoid is defined to be the *topography*. The definition is identical to the definition for land topography, for example the heights given on a topographic map.

The ocean's topography is caused by tides and ocean surface currents, and we will return to their influence in chapters 10 and 18. The maximum amplitude of the topography is roughly ± 1 m, so it is small compared to the geoid undulations.



Measurement of sea surface height from radar altimetry

A satellite altimeter measures the height of the satellite above the sea surface, Figure (A). When this is subtracted from the height of the satellite's orbit, the difference is sea level relative to the center of the Earth. The shape of the surface is due to variations in gravity, which produce the geoid undulations, and to ocean currents which produce the oceanic topography, the departure of the sea surface from the geoid. The reference ellipsoid is the best smooth approximation to the geoid.

The sea surface height is computed from altimeter range and satellite altitude above the reference ellipsoid. Sea surface height is often shown as a sea-surface anomaly or sea-surface deviation; this is the difference between the sea surface height at the time of measurement and the average sea surface height for that region and time of year. The higher the sea surface height anomaly, the warmer the layer of water. The ground height or the sea surface height is measured from the **reference ellipsoid**. If the altitude of the satellite H_s is given as the height from the reference ellipsoid, the **sea surface height** HSSH is calculated as follows. $HSSH = H_s - H_a$ where, H_a is measured distance between satellite and the sea surface. The sea surface height is also represented by the geoid height, H_g that is measured between the geoid surface and the reference ellipsoid and the **sea surface topography** DH.

Geoid undulations are caused by local variations in gravity, which are due to the uneven distribution of mass at the sea floor. Seamounts have an excess of mass due to their density and they produce an upward bulge in the geoid (Fig. B). Trenches have a deficiency of mass, and they produce a downward deflection of the geoid. Thus the geoid is closely related to bathymetry; and maps of the oceanic geoid have a remarkable resemblance to the bathymetry. Seamounts are denser than sea water, and they increase local gravity causing a plumb line at the sea surface (arrows) to be deflected toward the seamount. Because the surface of an ocean at rest must be perpendicular to gravity, the sea surface and the local geoid must have a slight bulge as shown. Such bulges are easily measured by satellite altimeters. As a result, satellite altimeter data can be used to map the sea floor. Note, the bulge at the sea surface is greatly exaggerated; a two-kilometer high seamount would produce a bulge of approximately 10 m.

Geopotential

The potential energy per unit mass of a body due to the Earth's gravitational field as referred to an arbitrary zero reference level. A unit of geopotential is the potential energy acquired by a unit mass on being raised a unit distance in a gravitational field of unit strength.

Geopotential surface

A surface to which the force of gravity is everywhere perpendicular and equal. No work is necessary for the displacement of mass along a potential surface as long as no other forces act in addition to gravity. This can also be defined as a surface of equal dynamic height below the level of the sea surface, using the ideal sea

surface level as a reference surface with the potential value 0. This has also been called a potential surface or a level surface.

Geostrophic balance

A balance between the Coriolis acceleration and the pressure gradient (divided by the density) in a rotating fluid subject to gravitational restoring forces.

Geostrophic current

In oceanography, the theoretical current resulting from the balance of the pressure gradient force and the geostrophic force (Coriolis force) under frictionless horizontal motion, i.e. the forces associated with horizontal changes in density are compensated by accelerations arising from fluid motion on a rotating Earth. Analogous to the geostrophic wind in meteorology.

Glacial period

A time interval during which ice sheets have spread widely across lowlands in the north. During the last million years there have been four major glacial periods. In chronological order they are the Nebraskan, the Kansan, the Saale, and the Warthe-Weischel.

Gondwanaland

The name given to the hypothetical southern hemisphere supercontinent consisting of South America, Africa, Madagascar, India, Arabia, Malaya and the East Indies prior to its breakup. The northern hemisphere analogue was called Laurasia and both comprised a theoretical single supercontinent called Pangaea before breaking up.

Greenhouse effect

Short-wave solar radiation can pass through the clear atmosphere relatively unimpeded, but long-wave radiation emitted by the warm surface of the Earth is partially absorbed and then re-emitted by a number of trace gases in the cooler atmosphere above. Since, on average, the outgoing long-wave radiation balances the incoming solar radiation, both the atmosphere and the surface will be warmer than they would be without the green house gases.

Greenwich Mean Time

Mean Solar time referred to the zero meridian of longitude that passes through Greenwich, England. It is the basis for scientific and navigational purposes. It is also called UTC now a days meaning Universal Time Coordinated.

Gregorian calendar

The name given to the civil calendar now used in most countries of the world. It is the Julian calendar as reformed by the decree of Pope Gregory XIII in 1582. This reform omitted certain leap years and brought the length of the year on which the calendar is based nearer to the true astronomical value. It was designed to stay synchronous with the equinoxes.

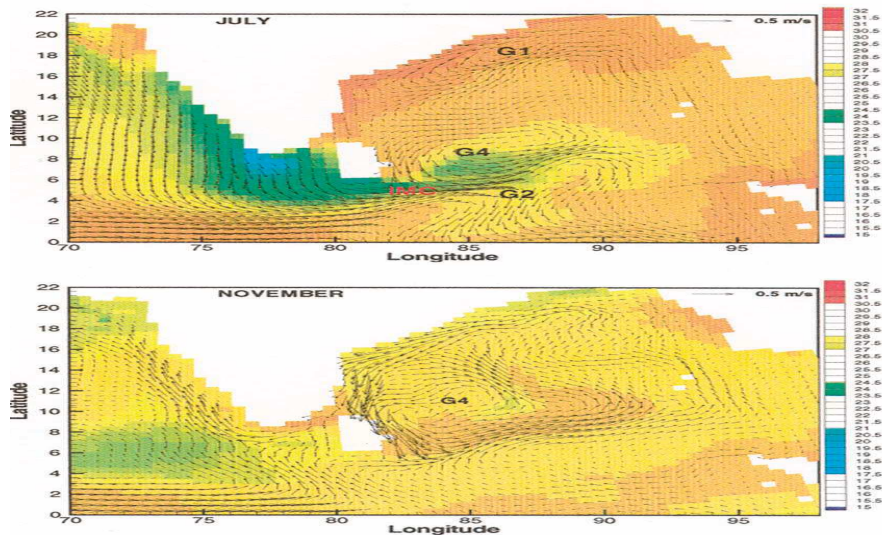
Gross Primary Production

The total amount of carbon (or organic matter or energy) fixed by an ecosystem, including the amount fixed but respired by the green plants.

Ground truth data

Geophysical parameter data, measured or collected by means other than by the instrument itself, used as correlative or calibration data for that instrument data, including data taken on the ground or in the atmosphere. Ground truth data are another measurement of the phenomenon of interest; they are not necessarily more "true" or more accurate than the instrument data.

Gyres in Bay of Bengal:



The Figure shows the Circulation in the Bay of Bengal for the months of July and November from the model simulation of Haugen et al. [2002] Haugen et al. (2002) used the Miami Isopycnic Coordinate Ocean Model (MICOM) to simulate the Indian Ocean circulation. A major result of Haugen et al. (2002) is the discovery of a new cyclonic gyre in the Bay of Bengal, G4 which is cyclonic

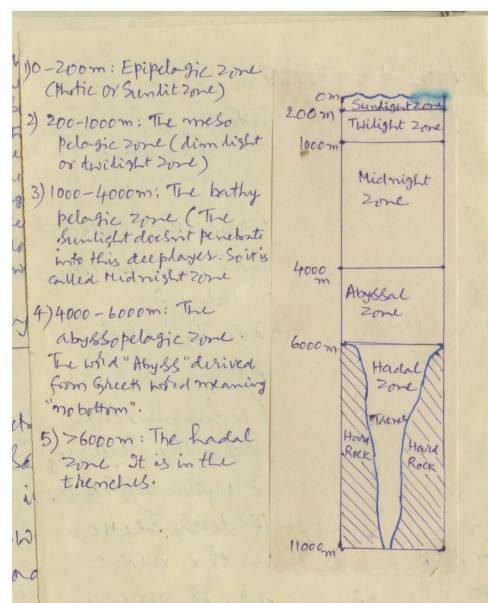
while discussing the four gyres (G1, G2, G3, and G4 in the seasonal cycle of Bay of Bengal circulation. Vinayachandran and Yamagata (1998) (VY) used a seasonal simulation by the GFDL Modular Ocean Model (MOM) to study three gyres in the Bay of Bengal. A cyclonic gyre east of Sri Lanka during summer, another cyclonic gyre in the southwestern Bay of Bengal during winter, and an anticyclonic gyre south of Sri Lanka during summer (Figure 1). The gyre called G4 by Haugen et al. (2002) is called Sri Lanka dome during summer and Bay of Bengal dome during winter by VY. VY has shown that the cyclonic gyre east of Sri Lanka during summer and winter is forced by local Ekman pumping.

Guyot

A guyot is a seamount with a flat top created by wave action when the seamount extended above sea level. As the seamount is carried by plate motion, it gradually sinks deeper below sea level.

Hadopelagic zone or Hadal zone

One of five vertical ecological zones into which the deep sea is sometimes divided. It is the lowest of the levels and is separated from the overlying abyssopelagic zone at about 6000 meters in the trenches.



Halocline

In oceanography, a relatively sharp change in salinity with depth.

Heard Island Feasibility Test (HIFT)

An ocean acoustical tomography experiment in which computed geodesics (minimum paths) for acoustics transmissions were compared with observations.

The acoustic source was suspended from the R/V *Cory Chouest* 50 km southeast of Heard Island located about halfway between Africa and Australia at about 50 ° S in the South Indian Ocean. Receiver arrays were located on various research vessels throughout the oceans as well as at South Africa, Bermuda, India, Christmas Island, Samoa, Hobart (Tasmania) and Monterey (California).

Heat capacity

The heat capacity of a body is the product of its mass and its specific heat.

Horse latitudes

The belts of variable, light winds and fine weather associated with the subtropical anticyclones. The name originated with the historical sailing practice of throwing the horses being transported to America or the West Indies overboard when these latitudes were reached and the light winds caused the voyage to be overly extended.

Hydrography

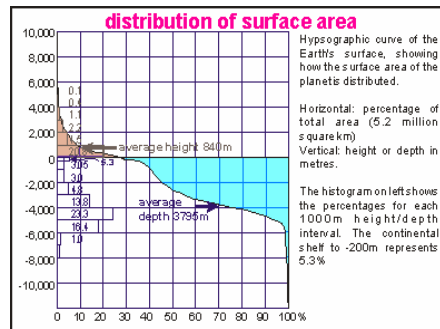
The study of the physical features of water bodies like oceans and lakes (in analogy to geography being the study of the physical features on land). Oceanic features of interest include the location and spatial extent of water masses as identified by their characteristic properties such as salinity, temperature and micronutrient concentrations. Early systematic attempts at applying hydrography to the oceans were the core layer method and the isopycnal method in the 1920s and 1930s by Wüst, Iselin, Montgomery, Defant and others, and variants of these methods are still used today to provide a first-order general classification of the waters of the world ocean. Much care, however, should be taken when attempting to use the results of these mostly static classification methods to understand the dynamical aspects of the ocean (although the latter is much more closely related to dynamical fields). This is best exemplified by the classic apothegm "the hydrographer's ocean is much smoother than the dynamicist's ocean".

Hydrosphere

This consists of all water in the liquid phase distributed on the Earth, including the oceans, interior seas, lakes, rivers, and subterranean waters.

Hypsometric curve

A plot of the percentage of elevation and depth distribution on the continents and oceans.



IAPSO

Abbreviation for International Association for the Physical Sciences of the Oceans. A member of the ICSU.

ICW

Abbreviation for Indian Central Water.

Indian monsoon

The seasonal reversal of the wind direction along the shores of the Indian Ocean, especially in the Arabian Sea. The winds blow from the southwest during half of the year and from the northeast during the other half. The reversal of direction (from that due to the normal zonal circulation pattern) is due to the effects of differential heating as the Himalayan plateau heats up during the summer, causing the air to rise and be replaced by the warm, moist air from over the Indian Ocean.

Indian Ocean circulation

It is in the wind-driven equatorial current system and in its northern parts that the Indian Ocean circulation differs most from those in the Atlantic and Pacific. Because of the land mass to the north of the equator and the ocean to the south of the equator there is a seasonal variation in the winds over the Indian Ocean and the Indian subcontinent. From November to March, these winds blow from the north-east (north-east Trades or North-east Monsoon), from May to September they blow from the south-west (South-west Monsoon). (The word monsoon is derived from an Arabic word *mausam* meaning change of winds, which change with the seasons.)

The South-West Monsoon winds are really a continuation across the equator of the South-East Trades, which continue throughout the year. The change of wind direction north of the equator then results in a change of currents there as well as a complete change of weather for the Indian subcontinent. The warm, wet-weather associated with the South-West Monsoon is generally referred to as “the monsoon” which in general refers to relatively continuous rains in India during the south-west monsoon. In contrast the north-east monsoon brings dry continental air-masses to India resulting in dry and cool weather.

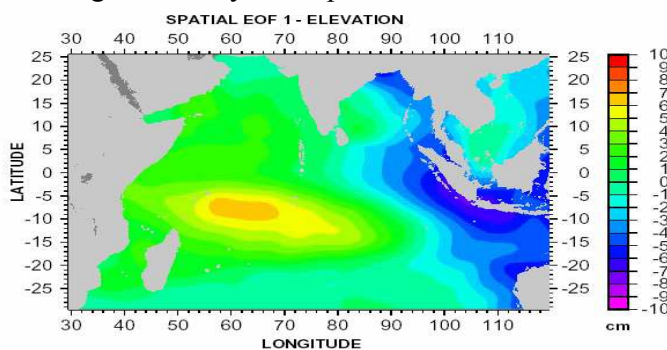
During the northeast monsoon (November to March) there is a westward-flowing North Equatorial Current from 8 °N to the equator; from the equator to 8 °S there is the eastward-flowing Equatorial Countercurrent and from 8 °S to between 15 and 20 °S there is the South Equatorial Current to the west. During the south-west monsoon (May to September) the flow north of the equator is reversed and is to the east. This combines with the eastward ECC and the whole eastward flow from 15 °N to 7 °S is called the (South-west) Monsoon Current. The SEC continues to the west south of 7 °S but is stronger than during the north-east monsoon

An Equatorial Undercurrent is found in the thermocline east of 60 °E during the north-east monsoon period. It is weaker than those in the Pacific and Atlantic. During the South-west Monsoon, with the general flow to the east at the equator, the EUC is not evident. The transition from one monsoon to the other happens relatively rapidly, occurring over a period of 4-6 weeks in April and October. This provides oceanographers with an interesting opportunity to observe the temporal development of wind-driven ocean currents during the reversal period. In going from the November-March north-east monsoon to the south-west monsoon the change takes place during the month of April.

While the wind appears to shift rather abruptly, when the pressure systems shift, the ocean currents change more slowly (Düing, 1970). During this transition period the ocean circulation, particularly in the west-central Indian Ocean, breaks into a series of cold and warm mesoscale eddies which eventually transition into the reversed ocean circulation in harmony with the reversal of the wind driving. A simple, linear, barotropic model (Düing, 1970) was used to simulate many of these features during the transition and was successful in reproducing the general patterns seen in a collection of oceanographic measurements. The reverse transition takes place in October when the wind systems shift from the Southwest to the North-east Monsoon and the earlier pattern returns.

Indian Ocean Dipole

From the figure below the two poles of the Indian Ocean dipole are easily recognized from the large negative values of sea level off southern Sumatra (cooling, blue) and the large positive values at 7°S, 62°E (warming, orange). This is called the Indian Ocean Dipole. This figure is derived from Topex/Poseidon sea level height anomaly data-spatial EOF-I elevation at international time scales.



Indian Ocean Warm Pool (IOWP)

The minimum SST required for active convection is 28° C. A large region of tropical ocean with SST >28° C, called Warm Pool, lies in the central Indian Ocean. The area of Indian Ocean Warm Pool (IOWP) change three fold during a year from a minimum of 8×10^6 km² during September to a maximum of 24×10^6 km² during April. The warming phase of IOWP begins in February, when the pool begins to spread on both sides of the equator.

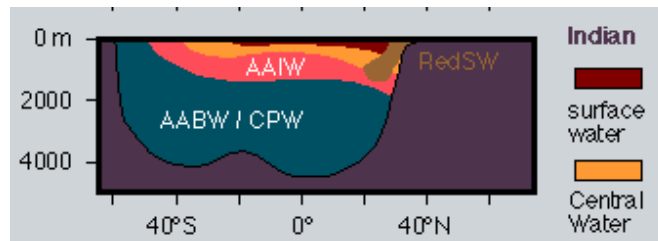
Indian Ocean water masses

The surface water masses in the open Indian Ocean have typical characteristics, a substantially zonal distribution of the isotherms with a temperature maximum near the equator and a salinity maximum at about 30°S in the eastern ocean. This is somewhat farther south than in the Atlantic and Pacific. In the north, the Arabian Sea west of India and the Bay of Bengal to the east has very different characteristics. The Arabian Sea has high surface salinity values up to 36.5 psu, due to evaporation, while in the Bay of Bengal the salinity decreases from about 34 psu at about 5°N to 31 psu or less in the north. The low values in the Bay of Bengal are due to the very considerable river runoff into it (all of the Indian rivers terminate on the eastern side of the sub-continent), particularly during the south-west monsoon. Some of this low-salinity water is carried westward while heavy rainfall in the Intertropical Convergence Zone contributes to the low salinity in the northern part of the SEC.

Below the surface layer and north of 10°S there is the Indian Equatorial Water or North Indian High-salinity Intermediate Water (Wyrcki, 1973). This water has a relatively uniform salinity of 34.9 to 35.5 psu. Some of it is formed in the Arabian Sea but there are also components from the Red Sea and the Persian Gulf with values to 36.2 psu. It also spreads into the Bay of Bengal. Wyrcki points out that the waters of the northern monsoon gyre are separated from the (southern) subtropical waters by a boundary or front which is inclined from about 100 m depth at 10 °S to 1,000 m depth at 20 °S. North of this front, the water is saline, low in oxygen and high in nutrients while to the south the reverse is the case. South of the equator to about 40 °S and to 1,000 m is the Indian Central Water of the southern gyre of the ocean with salinities from 34.5 to 36 psu; under this is the Antarctic Intermediate Water.

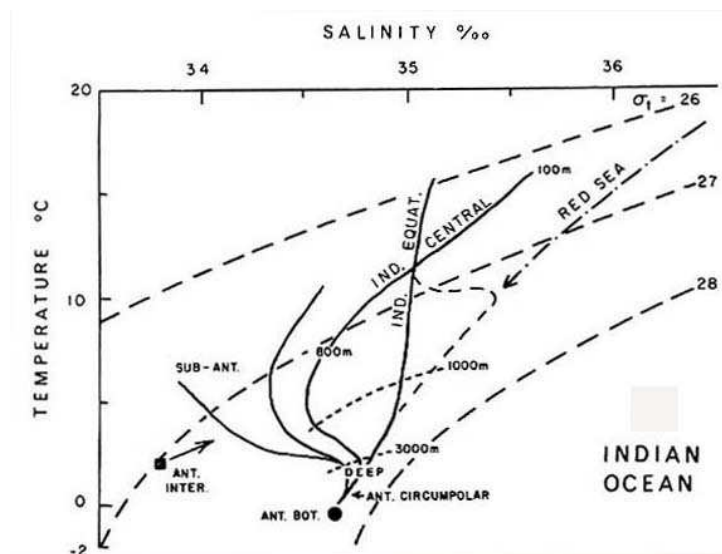
Both the Deep and Bottom Waters are of Atlantic/Antarctic origin, as no waters of these types are formed in the Indian Ocean. As in the Pacific Ocean the circulation of these waters appears to be slow and must be inferred from the property distributions. The Deep Water properties are 2°C and 34.8 psu, essentially those of Montgomery's "Common Water". A flow of Bottom Water to the north in the west and east basins (separated by the mid-ocean ridge) is inferred from a slight increase in potential temperature to the north attributed to geothermal heating from below. A very noticeable feature of the deep waters is the decrease in dissolved oxygen from 5 mL/L in the Antarctic waters to 0.2 mL/L in the Arabian Sea and Bay of Bengal. This is attributed to the recent

formation and continued movement of the southern waters contrasted with the isolation and stagnation in the north. This situation is in contrast with that in the Atlantic and Pacific where the most notable regions of low oxygen are on the east side around the equator.



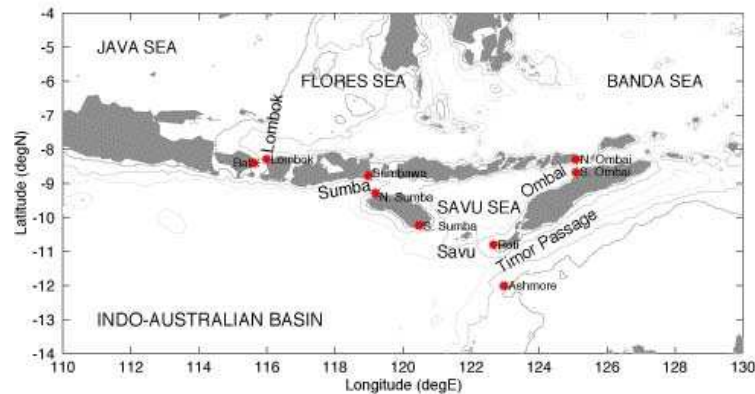
Sketch of the water mass distribution in the Indian Ocean. AABW: Antarctic Bottom Water, CPW: Circumpolar Water, AAIW: Antarctic Intermediate Water, RedSW: Red Sea Water, gold: Central Water, brown: surface water.

Indian ocean T-S diagram



These temperature-salinity properties are summarized here in the mean TS curves of Fig. 13.10 which shows the mean curves as well as individual such as that for the Red Sea. The Red Sea injects high salinities into the subsurface portion of the Indian Ocean. These high salinities are only eclipsed by the Central Water in its highest temperature portions. Regarding upper waters the Indian Ocean divides into equatorial and central water masses. The fact that the Antarctic Intermediate Water (AIW) is present in the Central Water demonstrates that it is south of the Equatorial Water which does not contain any expression of the AIW.

Indonesian through flow



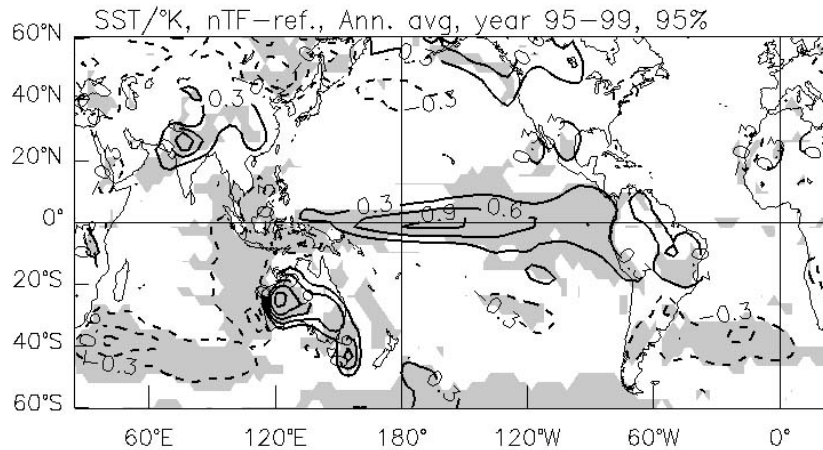
Flow from the Pacific to the Indian ocean via the complicated series of passages and sills that make up the Indonesian archipelago as shown in the figure below is a one way movement of significant amounts of freshwater and heat is called the Indonesian through flow. This flow is linked to the regional climate of the Australasian region and to the large-scale structure of the global thermohaline circulation. The figure shows the Indonesian Archipelago. Lines indicate the 200,1000 and 2000 meter isobaths and the red dots indicate the location of shallow pressure gauges.

From 1995-1999, measurements were made of the upper layer throughflow in the principal straits between Bali and Timor that connect the Indian Ocean to the Indonesian Seas. Nine shallow pressure gauges, equipped with temperature and conductivity sensors, were deployed in December 1995 and finally recovered in May 1999. In addition, repeat (150 kHz) ADCP surveys of each strait were made on the 4 cruises as time allowed.

Pressure differences across the various straits are related to the mean shallow geostrophic velocity through the strait, an assumption substantiated by comparison with direct velocity measurements. The ADCP sections suggest that the shallow velocity is linearly correlated with transport in the upper 100 m to within ± 0.5 Sv. Thus, time-series of these pressure differences represent the first simultaneous measurements of surface geostrophic transport (and its properties) through all the principal straits and passages linking the Pacific to the Indian Ocean. The pressure gauge data alone can only determine velocity fluctuations relative to an unknown temporal mean. Absolute velocity is estimated by a best fit to the mean 25 m ADCP measurements, averaged over several tidal cycles.

The shallow pressure gauge array fortuitously captured the inception and passing of the 1997/98 El Niño and provides an unprecedented snapshot of the throughflow in the outflow straits during this event. With continued monitoring, the network could be very useful towards understanding the response of the throughflow to the strong interannual variations in the equatorial Pacific.

Model studies (<http://meteora.ucsd.edu/~niklas/WORK/INDO.html>) suggests that dramatic global changes in surface temperature and wind would occur if the Indonesian Throughflow was cutoff for a period. As an example the sea surface temperature changes in a model with a closed throughflow is shown below.



This Figure shows the Changes in SST in °C due to the closure of the Indonesian throughflow; there are the differences from a 5-year average of a coupled model with a close throughflow from a 100 year of a run with a normal open throughflow. Shaded areas indicate where changes are significant at the 95 % level

Infrared

That part of the electromagnetic radiation spectrum from approximately 0.75 to 1000 μm . This is between the visible and microwave regions of the spectrum. It is further divided into the near (0.75 to 1.5 μm), intermediate (1.5 to 20 μm), and far (20 to 1000 μm) ranges. Most of the energy emitted by the Earth and its atmosphere is at infrared wavelengths, and it is generated almost entirely by large-scale intramolecular processes. The tri-atomic gases such as water vapor, CO₂, and ozone absorb infrared radiation and play important roles in the propagation of infrared radiation in the atmosphere.

Inshore

The zone or portion of a beach profile extending seaward from the foreshore to just beyond the breaker zone.

in situ data

Data associated with reference to measurements made at the actual location of the object or material measured, by contrast with remote sensing (i.e., from space).

Insolation

The radiation received from the Sun. Incoming Solar Radiation.

Interannual variability

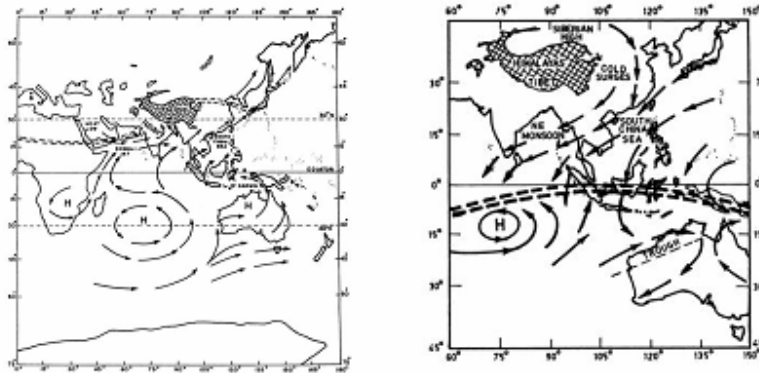
A phenomena which changes from year to year as opposed to the annual variability due to the seasonal cycle. The ENSO phenomena is an example of this.

International Indian Ocean Expedition (IIOE)

A research program under which scientists of twenty-two nations collected data in the Indian Ocean from 1959-1965. This was done under a plan coordinated by the Scientific Committee on Oceanographic Research (SCOR) of UNESCO.

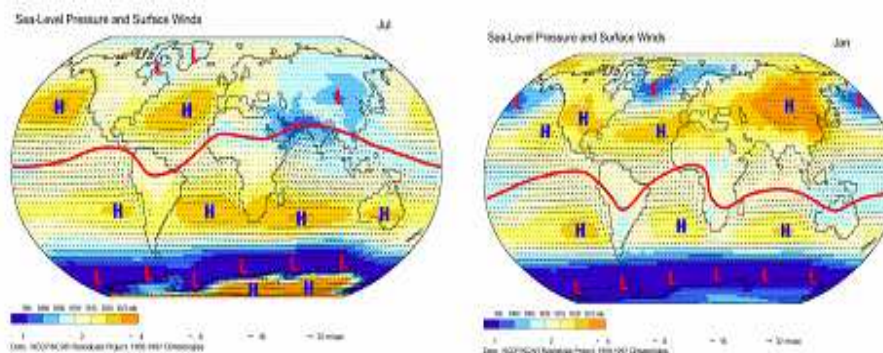
Intertropical Convergence Zone (ITCZ)

A narrow low-latitude zone in which air masses originating in the northern and southern hemispheres converge and generally produce cloudy, showery weather. It is the boundary between the northeast and southeast trade winds. The mean position is somewhat north of the equator over Indian Ocean and migrates with season. During south west monsoon season it is called Monsoon trough and is over the Himalayas and during winter or northeast monsoon season it is south of the equator. Often it is abbreviated as ITCZ.



Position of ITCZ (dashed line) during southwest monsoon(left figure) and northeast monsoon (right figure) in India

This ITCZ migrates to north and south in summer and winter respectively as shown by the red curve in the figure below. The annual cycle of differential heating and cooling in the Indian Ocean gives rise to extraordinary, meridional excursions of the ITCZ. Heavy rainfall and reversal of wind stress accompany the semi-annual sweeps of ITCZ across the north Indian Ocean. The effects are more pronounced in the Arabian Sea where south west monsoon winds attain higher speeds in the form of a concentrated air flow commonly known as the Findlater Jet.



The Left indicates the ITCZ (red line) during South west monsoon and right during North east monsoon over India

Inversion

In meteorology, a reversal of the usual temperature gradient in the atmosphere with the temperature increasing with height. These occur frequently near the ground on cold nights and in anticyclones, often causing dense smoke fogs over cities. But in oceanography if temperature increases with depth instead of decrease then it is called inversion.

Irradiance

The radiant energy that passes through a unit horizontal area per unit time coming from all directions above it. The irradiance F_i is defined by

$$F_i = \int_0^{2\pi} I \cos \theta d\omega$$

where I is the radiance, θ the zenith angle, and $d\omega$ the infinitesimal solid angle. The rate at which radiation is incident upon a unit area.

Island arc

The island arc is composed of volcanos produced when oceanic crust carried deep into a trench melts and rises to the surface.

Isobar

In physical oceanography, a contour of constant pressure.

Isohaline

In physical oceanography, a contour of constant salinity.

Isopycnal

In physical oceanography, a contour of constant density.

Isostere

In meteorology, a line on a chart joining points of equal specific volume, the volume of unit mass.

Isotherm

In physical oceanography, a contour of constant temperature.

Isotope

Each of two or more varieties of a particular chemical element which have different numbers of neutrons in the nucleus, and therefore different relative atomic masses and different nuclear (but the same chemical) properties.

Jet stream

A well-defined core of strong wind, ranging from 200-300 miles (320-480 km) wide with wind speeds up to 200 mph (320 kph), that occurs in the vicinity of the tropopause.

JGOFS

Acronym for Joint Global Ocean Flux Study, a subprogram of the IGBP whose goal is to improve our knowledge of the processes controlling carbon fluxes between the atmosphere, surface ocean, ocean interior and its continental margins, and the sensitivity of these fluxes to climate changes.

Joule

The unit of work or energy in the MKS System of units. It is the work done by a force of one newton in moving its point of application one meter in the direction of the force. Some equivalences are: 1 joule = watt sec = 10^7 ergs; 1 calorie = 4.1868 joules.

JPOTS

Abbreviation for Joint Panel on Oceanographic Tables and Standards, a panel sponsored by UNESCO, ICES, IAPSO, and SCOR which first met in 1962 (in an earlier form not yet called JPOTS) to study and decide upon standards to measure the properties of sea water.

Julian calendar

A system of keeping years and months for civil purposes based on a tropical year of 365.25 days. It was instituted by Julius Caesar in 45 BC and is still the basis of the calendar, although it was modified and improved to create the Gregorian calendar.

Julian days

The number of days which have elapsed since 12:00 GMT on Jan. 1, 4713 BC. This system of numbering by consecutive days gives a calendar independent of month and year and is used for analyzing periodic phenomena. This system, devised in 1582 by J. Julius Scaliger and used most extensively by astronomers, has no connection with the Julian calendar other than the similar name.

Kelvin

The SI unit of thermodynamic temperature. It is defined as $1/273.16$ of the temperature of the triple point of water above absolute zero. The symbol for this is K.

Kelvin wave

A type of coastally trapped wave motion where the velocity normal to the coast vanishes everywhere. The wave is nondispersive and propagates parallel to the shore with the speed of shallow water gravity waves, i.e. \sqrt{gH} . The profile perpendicular to shore either decays or grows exponentially seaward depending on whether the wave propagates with the coast to its right or left (in the northern hemisphere). For vanishing rotation, the decay or growth scale becomes infinite

and the Kelvin wave reduces to an ordinary gravity wave propagating parallel to the coast. The dynamics of a Kelvin wave are such that it is exactly a linearized shallow water gravity wave in the longshore direction and exactly geostrophic in the cross-shore direction.

Kirchhoff's law

In radiation transfer, a law stating that in thermodynamic equilibrium and at a given wavelength the ratio of the intensity of emission I_λ to the absorptivity a_λ of any substance does not depend on the nature of the substance but rather only on the temperature and the wavelength, i.e.

$$I_\lambda / a_\lambda = f(\lambda, t).$$

Another way of saying this is the the absorptivity and emissivity of a substance are equal and any single wavelength.

KNMI

Abbreviation for the Royal Netherlands Meteorological Institute (i.e. Koninklijk Nederlands Meteorologisch Instituut).

Knot

A speed of 1 nautical mph. It is equal to 1.15 mph or 1.85 kph and used in navigation and meteorology.

Knudsen's Tables

A series of tables published in 1901 that allowed one to find the density of a sea water sample (relative to pure water) as a function of its measured chlorinity, salinity and temperature. These tables allowed the easy determination of the density (at atmospheric pressure and in situ salinity and temperature, i.e. σ_t) and the thermosteric anomaly from measured quantities.

Lafond's tables

A set of tables compiled by E. C. La Fond for the purpose of correcting reversing thermometers and computing dynamic height anomalies. These were published by the U.S. Navy Hydrographic Office as H. O. Pub. No. 617.

Latent heat

The quantity of heat absorbed or emitted, without change of temperature, during a change of state (from solid to liquid or from liquid to gas) of a unit mass of a material. It is a hidden heat (i.e. it can't be sensed by humans) that doesn't occur until phase changes occur. An example is the evaporation of liquid water cloud droplets cooling the air by removing heat and storing it as latent heat. Phase changes that cool the air are vaporization (liquid to vapor), melting (solid ice to liquid) and sublimation (solid to vapor), while phase changes in the opposite direction that warm the air are condensation (vapor to liquid), fusion (liquid to

solid) and deposition (vapor to ice). The latent heat is $2.5 \times 10^6 \text{ J/kg}^{-1}$ for condensation or evaporation, $3.34 \times 10^5 \text{ J/kg}^{-1}$ for fusion or melting, and $2.83 \times 10^6 \text{ J/kg}^{-1}$ for deposition or sublimation, with the sign depending on the direction of the change.

Latent heat flux

The exchange of heat between a moisture-containing surface and atmosphere resulting mainly from the evaporation at the surface and the later condensation within the atmosphere. This is an indirect transfer of heat associated with the phase transitions of water, between liquid and vapor at the surface and later between vapor and liquid or solid phases.

Latitude

The distance of a point north (positive) or south (negative) from a given reference point.

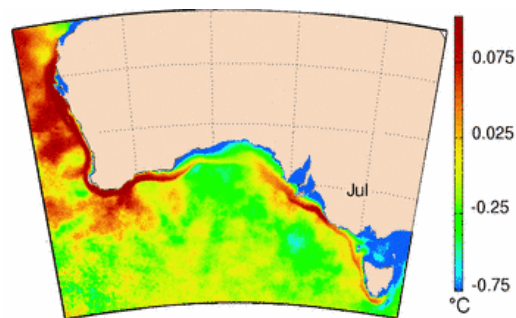
Leeuwin Current

Along the eastern boundary of the Indian Ocean, off Western Australia, the Leeuwin Current, identified about 1970, differs from other eastern boundary currents. It is a poleward flowing current about 100 km wide and 2,000 km long along the continental shelf-break from about 22 °S, off the Northwest Cape, to the southwestern tip of Australia (Cape Leeuwin) at 35 °S. The current then turns eastward toward the Great Australian Bight. Godfrey and Ridgway (1985), Thompson (1984) have presented descriptions and theoretical explanations. The current reaches its maximum speed of 60 cm/s in May with a poleward flow at 32.5 °S of 3-5 Sv in the upper 150 m and there is an equatorward flow of up to 40 cm/s at 300 m depth with a transport of 1-2 Sv below this. At this time, the wind stress is equatorward and therefore the upper flow is against the wind, in contrast to that in other eastern boundary regions.

The flow appears to be driven by a steric sea-level slope of about 0.33 m downward from 20 °S to 32 °S. Another characteristic of the Leeuwin Current is that upwelling does not occur on to the shelf. The isotherms off Western Australia slope strongly downward from about 200 km offshore to the continental slope, in contrast to the situation in the regions off the western United States (30 °N), off South Africa (26.5 °S) and off South America, where the isotherms slope upward toward the shore and upwelling of cool water occurs. In addition, there are both cyclonic and anticyclonic eddies in the Leeuwin Current region, in contrast to that off the east coast of Australia where the eddies are anticyclonic only.

The Leeuwin Current (in the upper 150 m) is warm and of relatively low salinity (35.0 psu), low dissolved oxygen and high phosphate content, while the equatorward cool undercurrent has a core of high salinity (>35.8 psu) at 38 °S.

The Leeuwin Current therefore transports a significant amount of heat to the south. It is suggested that the cause of the poleward downslope, to which the Leeuwin Current is attributed, is flow from the Pacific through the Indonesian archipelago to the Indian Ocean north of Western Australia. This is combined with the seasonal monsoon winds in this area which have peak values to the southeast in January/February and whose stress raises sea-level north-east of Australia and generates a wave of some sort which progresses southward down the Australian coast (since the peak flow occurs progressively later down the coast).



This differs from other eastern boundary currents in that an abnormally large pressure gradient overrides the usual scenario of equatorward winds producing surface upwelling, an equatorward surface flow, and a poleward undercurrent. The Leeuwin Current flows strongly poleward against equatorward winds due to a difference in dynamic height of 0.5 m along the coast. This difference is related to the throughflow from the Pacific to the Indian Ocean through the Australasian Mediterranean Sea which serves to maintain the same steric height on either side of the throughflow. The same height cannot be maintained by the colder waters off southwest Australia and thus the lower steric height. The result is a self-perpetuating process where the southward flow of warm water leads to surface cooling which keeps the steric height lower which leads to southward flow, etc. The annual mean transport of the Leeuwin Current has been estimated at 5 Sv with average current velocities ranging from 0.1-0.2 m/s, although its intensity and southward extent vary seasonally. It is strongest in May when the countering wind is weakest with speeds up to 1.5 m/s. The strong fronts on both sides of the current tend to produce eddies during this period.

Longshore bar

A ridge of sand running roughly parallel to the shoreline which may become exposed at low tide. There can be a series of these running parallel to one another at different water depths.

Low pressure center

In meteorology, a region of relatively low barometric pressure. These are characterized by upward moving air at altitude and convergence near the ground. These predominate in midlatitudes, i.e. around 40-50°. These are also known as cyclones and as such rotate clockwise/counterclockwise in the southern/northern hemisphere. Low pressure systems are generally characterized by clouds, precipitation, and occasionally thunderstorms, all of which are facilitated by the upward movement of moist air from near the ground.

Lower high water (LHW)

The higher of two high waters on a day when the tide is neither the lower of two low waters on a day when the tide is neither predominantly diurnal nor predominantly semidiurnal but rather intermediate to either (a situation sometimes called a mixed tide).

Lower high water interval (LHWI)

The time interval between the transit of the moon over either the local or Greenwich meridian and the next lower high water (LHW). This is generally used when the diurnal inequality is large.

Lower low water (LLW)

The lower of two low waters on a day when the tide is neither predominantly diurnal nor predominantly semidiurnal but rather intermediate to either (a situation sometimes called a mixed tide).

Lower low water interval (LLWI)

The time interval between the transit of the moon over either the local or Greenwich meridian and the next lower low water (LLW). This is generally used when the diurnal inequality is large.

Meridian

The great circle passing through the poles of the celestial sphere which cuts the observer's horizon in the north and south points and also passes through his zenith angle.

Mesopelagic zone

One of five vertical ecological zones into which the deep sea is sometimes divided. This is the uppermost aphotic zone from 200 to 1000 m deep where little light penetrates and the temperature gradient is even and gradual with little seasonal variation. This zone contains an oxygen minimum layer and usually the maximum concentrations of the nutrients nitrate and phosphate. This overlies the bathypelagic zone and is overlain by the epipelagic zone.

Meteorological equator

The latitude of the mean annual position of the equatorial trough. This is located at about 5°N rather than on the geographical equator.

Mixed layer

In oceanography, a nearly isothermal surface layer of around 40 to 150 m depth caused by wind stirring and convection. In the winter, low surface temperatures and large waves (with their accompanying turbulent mixing) can deepen the mixed layer all the way to the permanent *thermocline*thermocline. Higher temperatures and a less energetic wave climate in the summer can lead to the development of a seasonal thermocline at the base of the mixed layer that overlies the permanent thermocline.

Mode Water

A type of water created by property modification in the vicinity of ocean fronts, especially during winter. Convection creates a deep surface layer containing water of nearly uniform temperature and salinity in regions that usually feature strong horizontal and vertical gradients.

MODIS

Abbreviation for Moderate-Resolution Imaging Spectroradiometer, an instrument built to fly on EOS AM-1 and that will view the entire Earth's surface every 1 to 2 days acquiring data in 36 spectral bands to improve our understanding of global dynamics and processes occurring on the surface of the Earth, in the oceans, and in the lower atmosphere.

MONEX

Acronym for Monsoon Experiment, the summer and winter Asian Monsoon Experiments, a component of FGGE designed to study monsoonal circulations.

Mozambique Current

A western boundary current that flows south-southwestward between the African coast and Madagascar from about 10 to 35° S. The flow has been estimated at about 6 Sv near 15° S increasing to 15 Sv near 20° as the northward looping East Madagascar Current turns back towards the south and joins it. This combined flow eventually becomes the major part of the Agulhas Current.

Nansen, Fridtjof

A Norwegian scientist, diplomat and humanist who did much to advance the field of oceanography from the last decade of the 19th century until his death in 1930. He is the only oceanographer to ever win the Nobel Prize (in 1922), although he won it for his humanitarian work to aid refugees throughout Europe and Asia. He investigated many aspects of the northern Polar Regions, crossing the Greenland inland ice on his first polar expedition at the age of 27 in 1888 (after defending his dissertation in zoology on the histology of the central nervous system of the hagfish).

In 1892 he started planning what became known as the FRAM expedition, named after the polar vessel he specially constructed for this North Pole expedition. The significant results gained from that expedition included the discovery of a deep Arctic Ocean, the confirmation of the existence of a Transpolar Current, and observations of pack ice drift relative to the prevailing wind direction which

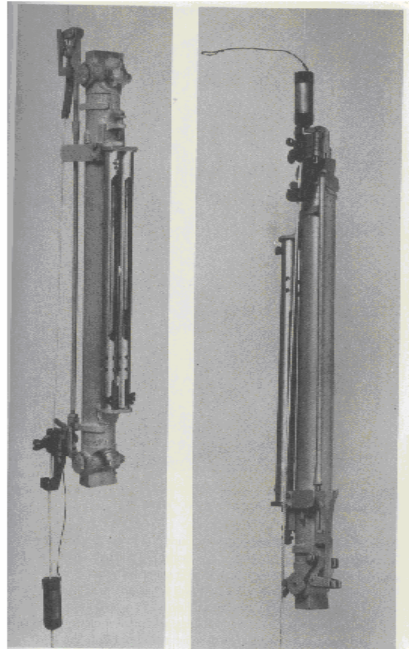
provided the impetus for the later identification of the Ekman Spiral (one of the cornerstones on which the modern theory of wind-driven circulation is built). The FRAM expedition and those that followed were also marked by careful measurement and compilation of data, detailed planning, and forceful execution, qualities that provided a firm baseline for all future expeditions.

Nansen had a strong practical bent as a scientist and explorer, improving old equipment and even inventing new equipment when the need arose. The most famous of his inventions was the Nansen bottle for sampling ocean water at various depths. He also strongly supported international cooperation in oceanography and, as a direct result, was one of the founding fathers of the International Council for the Exploration of the Sea (ICES) in 1902.

He became heavily involved in politics in his native Norway and played an important role in 1905 when Norway declared full independence from Sweden, which resulted in his being appointed the first Norwegian ambassador in London. After two years as ambassador, he returned to oceanography for several years until the advent of World War I, publishing the book *The Norwegian Sea* with B. Helland-Hansen during this period. He spent the remainder of his life after World War I engaged in various humanitarian activities until his death at age 60 in 1930, receiving his Nobel Prize in 1922.

Nansen bottle

This is a reversing water bottle comprising of 1200 ml of cylindrical barrel on either side of which two plug valves are attached with a connecting rod. This is made up of brass and usually coated either white or yellow and a pair of reversing thermometers frame also attached on its side. This was developed by Fridtjof Nansen around 1910.



Noise

In geophysical data processing this is most simply defined as any unwanted signal, and given that one person's signal can be another person's noise, this is ultimately a relative term. For example, if a time series is created by taking the temperature at some location every hour for five years, then the daily cycle of temperature that will be seen in such a record is a signal for someone looking for the daily cycle but is noise to someone looking for monthly or seasonal temperature variations.

Nonlinear

Said of a system (an electronic circuit, the climate, etc.) in which the output is not strictly proportional to the input. One consequence of this is that small changes in input can lead to very large and unpredictable changes in output.

North Equatorial Countercurrent (NECC)

An eastward flow in the Atlantic and Pacific located approximately between 5 and 10°N. It is located between the NEC and the SEC and called a countercurrent because it flows counter to the direction of the easterly trade winds. The NECC is strongest during July and August and weak in the northern winter and spring, and is known to migrate from a northernmost position in the northern summer to a position closest to the equator in the northern winter. Some evidence indicates that during this latter period the NECC is discontinuous and may even vanish in parts of the eastern Pacific. Even so, it is the most well developed of any of the equatorial currents. In the Indian Ocean this and the NEC are seasonally controlled by the monsoon circulation patterns.

North Equatorial Current (NEC)

A westward flow in the Atlantic and Pacific located north of the past 10° N. In the Indian Ocean this and the NECC are seasonally controlled by the monsoon circulation patterns.

Ocean stratosphere

The lower layer of the ocean as defined by Defant in 1928. The stratosphere is a sluggish, cold layer which is homogeneous vertically and horizontally in its basic properties. It is a region of slow exchanges.

Ocean troposphere

The upper layer of the ocean as defined by Defant in 1928. The troposphere is a region of relatively high temperature where there are strong vertical and horizontal variations of properties. It is a zone of perturbations and strong currents.

Offshore

The comparatively flat portion of a beach profile extending seaward from beyond the breaker zone to the edge of the continental shelf.

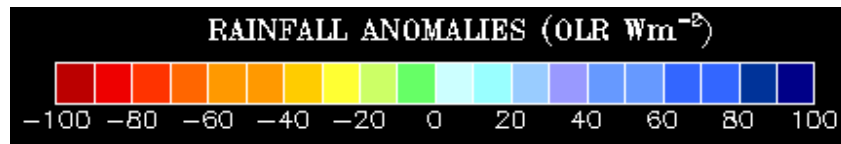
OLR

Abbreviation for Outgoing Longwave Radiation. This is controlled by the temperature of the emitting substance, so that the cold poles and cloud tops produce the lowest values. Deserts, with their warm surfaces and dry overlying atmospheres, show the highest values.

Satellites measure rainfall by looking at the outgoing long wave radiation or OLR, which is measured in watts per square meter (W m^{-2}). The amount of OLR emitted from clouds is determined by the cloud temperature; the lower the temperature, the lower the OLR. Because the satellite cannot penetrate clouds when measuring OLR it senses the temperature at the cloud tops.

The temperature of cloud tops depends strongly on cloud height; the higher the cloud, the colder it's top. Low cloud temperatures of course mean condensation and possibly rain. Experience shows that clouds which exceed a certain height inevitably cause rain on the ground. This is the basis for rainfall measurement from satellites: Low OLR means low cloud top temperature, which means large cloud height, which means large likelihood of rain on the ground.

The animation shows **OLR anomalies** and therefore has to be interpreted as departures from a reference average. This reference is itself a function of space and time, about which nothing can be learned from the distribution of anomalies. The only interpretation of OLR anomaly charts can be that positive OLR anomalies indicate less than average rainfall, negative anomalies suggest higher than average rainfall.



Optical thickness

A measure of the attenuation of solar radiation by the atmosphere that allows the convenience of considering as a single unit the losses due to scattering and absorption processes. The greater the thickness, the greater the attenuation of incoming solar radiation. This is also referred to as the optical depth.

Permanent thermocline

A relatively sharp change in temperature (and therefore density) beneath the seasonal thermocline maintained by a balance between downward diffusion of heat and the gradual upwelling of deep, cool water.

Persian Gulf

A marginal sea of the Indian ocean centered at approximately 52 °E and 27 °N. It is surrounded by Iran to the north, Kuwait, Saudi Arabia, Qatar, and the United Arab Emirates to the east and south, and connects with the Gulf of Oman (and on into the Arabian Sea) through the Strait of Hormuz to the east. It has a length of 990 km, ranges in width from 56 to 338 km, covers an area of 241,000 km², occupies a volume of 10,000 km³, has a mean depth of 40 m, and a maximum depth of about 170 m.

Peru Current or (Humboldt Current)

A component of the eastern limb of the counterclockwise-flowing southern subtropical gyre in the Pacific Ocean. The flow rate has been estimated at around 15 Sv, although variations from this can be considerable. This current is part of the most impressive Upwelling system in the oceans, with the upwelling driven by prevailing winds from the east that push the surface water westward, allowing the cold, nutrient-rich water beneath to well to the surface. Without the upwelling, this current lowers the temperatures along South America several degrees below the zonal average, and the upwelling serves to lower the temperatures without about 100 km of the coast another 2 to 4°C. The nutrient content of the upwelled water makes this region the most productive upwelling region in the world ocean, although a combination of overfishing and the effects of the El Nino phenomenon put an end to what was the largest fishery in the world before 1973.

The southern part of the Peru Current is sometimes called the Chile Current, and both were originally known as the Humboldt Current.



Plain

A flat, gently sloping or nearly level region of the sea floor. (For example, abyssal plain.)

Polar Front

In physical oceanography, a region of rapid transition in the Southern ocean between the Polar Frontal Zone and the Antarctic Zone. The position of the PF is usually indicated by the large temperature gradient along the temperature minimum of the Antarctic Surface Water (AASW) which starts to descend northward. The property indicators within the front are $\theta < 2$ ° along the θ -minimum at $Z < 200$ m, a θ -minimum at $Z > 200$ m, and $\theta > 2.2$ ° along the θ -maximum at $Z > 800$ m. The PF is one of three distinct fronts in the Antarctic Circumpolar Current the others being the Subantarctic Front (SAF) to the north and the Southern ACC Front (SACCF) to the south.

Polar Frontal Zone

In physical oceanography, the name given to a transition region in the Southern Ocean between the Subantarctic Front and the Polar Front. It is identified as a region bound by the 3-9 °C surface isotherms. The PFZ is one of four distinct surface water mass regimes in the Southern Ocean, the others being the Subantarctic Zone (SAZ) to the north and the Antarctic Zone (AZ) and Continental Zone (CZ) to the south.

Polynya

An oceanic area which remains either partially or totally ice free at times and under climatological conditions where the surface waters would be expected to be ice covered. They appear in winter when air temperatures are well below the freezing point of sea water and are bordered by water that is covered with ice. They are typically rectangular or elliptical in shape and occur quasi-continuously in the same regions. The size of polynyas can range from a few hundred meters to hundreds of kilometers.

Polynyas are of interest for several reasons. They are sites for active brine formation which may affect the local water density structure and current field and may also influence large-scale water mass modification. They are also a locus for gas exchange between the ocean and atmosphere in Polar Regions. The large sensible heat fluxes (along with fluxes due to evaporation and longwave radiation) tend to dominate regional heat budgets. They are also of biological interest since their regular occurrence makes them important habitats, e.g. the open water can lead to localized plankton blooms and large mammals tend to use them as feeding grounds.

There are two mechanisms for polynya formation. First ice may form within a region and is continuously removed by winds, currents, or both. Here the heat required to balance the loss to the atmosphere and hence to maintain the open water is provided by the latent heat of fusion of the ice that is continually formed. The second mechanism involves oceanic heat entering a region in quantities sufficient to prevent local ice formation. The first mechanism creates “latent heat polynyas” and the second “sensible heat polynyas”, and both mechanisms may operate simultaneously in the same region.

Potential density

A physical oceanographic term for the density of a sample calculated from its salinity, potential temperature, and at a selected pressure, i.e. $\sigma_\theta = \sigma(S, T_\theta, p)$. This is the effective density of a parcel of water after removing the heat associated solely with the effects of compression. Up until about 1970 calculations of potential density values were routinely performed with atmospheric pressure at the sea surface as the selected pressure, but later investigators found it sometimes convenient to instead calculate potential densities at other pressure levels. The 4000 dbar pressure level (abbreviated σ_4) is probably the next most often used level. Other levels (usually at 1000 dbar increments) are also sometimes used and similarly abbreviated.

Potential temperature

A physical oceanographic term for the temperature that a water sample gathered at depth would potentially have if brought adiabatically (i.e. without thermal

contact with the surrounding water) to the surface, i.e. the effective temperature of a water parcel after removing the heat of the parcel associated solely with compression. A sample brought from depth to the surface will, due to the slight compressibility of sea water, expand and therefore tend to cool, and as such potential temperatures at great depths are always less than measured temperatures.

In meteorology this is defined as a measure of temperature that removes the effects of dry adiabatic temperature changes experienced by air parcels during vertical motion. This can be calculated as

$$\theta = T \left(\frac{P_0}{P} \right)^{R_d/C_p}$$

where θ is the potential temperature, P_0 a reference pressure, R_d the gas constant for dry air and C_p the specific heat.

Power spectrum

The presentation of the square of the amplitudes of the harmonics of a time series as a function of the frequency of the harmonics.

Ppm(‰)

Abbreviation for parts per million (‰) or parts per mille. For example, average sea water salinity is 35 (‰).

Practical Salinity Scale (PSU)

In oceanography, this is a scale on which the salinity of ocean water is evaluated. It is a unit less scale that was developed to unify two separate salinity determination methods that were previously used for laboratory and in-situ measurements. The results are reported in a unit less manner since it is based on chlorinity ratios rather than measurements of absolute quantities, although the results are mostly consonant with earlier reports in units of parts per thousand.

Precession

The inclination of the earth's axis is approximately $23\frac{1}{2}^\circ$ from the vertical. This angle of inclination wobbles slightly like a slowing top. This wobbling is called the precession. The first is axial precession, where the earth's axis of rotation wobbles like a spinning top due to the torque of the sun and the planets on the non-spherical earth. Therefore the North Pole describes a circle in space with a period of 26,000 years. At present the northern end of the axis points to the polestar or northern star. This was not always the case. Some 13000 years ago when that end pointed in the opposite direction, the polestar was near the constellation of vega with which the entire universe is moving. The second is elliptical precession in which the ellipse that the earth's orbit is rotating about its

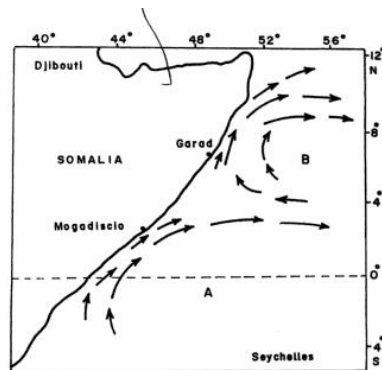
axis. Both effects combined are known as the "precession of the equinoxes" where the equinox (March 20 and September 22) and solstice (June 21 and December 21) shift slowly around the earth's orbit with a period of 22,000 years. The eccentricity modulates and splits the precession frequency into periods of 19,000 and 23,000 years. The precession causes warm winters and cool summers in one hemisphere and the opposite in the other, with the effect being largest at the equator and diminishing towards the poles.

Primary productivity

The amount of organic material produced by organisms from inorganic material. Most of the primary production in the oceans is due to photosynthesis of phytoplanktonic algae in the upper 100 m, i.e. the euphotic zone.

Prime eddy

The studies showed that a large eddy first formed in the Somali region approximately between 4°N and 12°N during late May or early June. Bruce (1979) called it as the 'Prime eddy' because it appears to be first formed in the region upon the commencement of the southwest monsoon. Prime eddy was considerably larger and more energetic than the other eddies formed during the season and it has been observed to remain in this location at least for 3 months after the cessation of the southwest monsoon. A smaller eddy associated with the Prime eddy was observed each year (1975-76) off Socotra between 12°N and 15°N. Also during another year (1976), a southern eddy was observed south of about 5°N and adjacent to the southern boundary of the prime eddy to the east of African coast. Observations indicate that northeastward flowing Somali Current is clearly part of the eddy field.



Pycnocline

In physical oceanography, a layer where density changes most rapidly with depth. It can be associated with either a thermocline or a halocline.

Quasi-Biennial Oscillation

The alternation of easterly and westerly winds in the equatorial stratosphere with an interval between successive corresponding maxima of 20 to 36 months. The regimes start at about 30 km and propagate downwards at about one kilometer per month.

Radar

An acronym for radio detection and ranging, the use of reflected electromagnetic radiation to obtain information about distance objects. The wavelength used is normally in the radio frequency spectrum between 30 m and 3 mm.

Radiance

The radiation energy per unit time coming from a specific direction and passing through a unit area perpendicular to the direction.

Radiosonde

A meteorological instrument package, suspended below a balloon, consisting of instruments to sense and relay temperature, humidity and pressure (an aneroid barometer) as it ascends through the atmosphere. The ascension rate is about 5 m/s and it can gather data up to about 30,000 meters.

Rawin

Acronym for radar wind sounding, the determination of winds by radar observation of a balloon.

Rawinsonde

A more advanced version of a radiosonde that also measures wind speed and direction.

Rayleigh scattering

The dominant wave scattering mechanism when the dimension of the region or object causing the scattering is much less than the wavelength of the wave being scattered

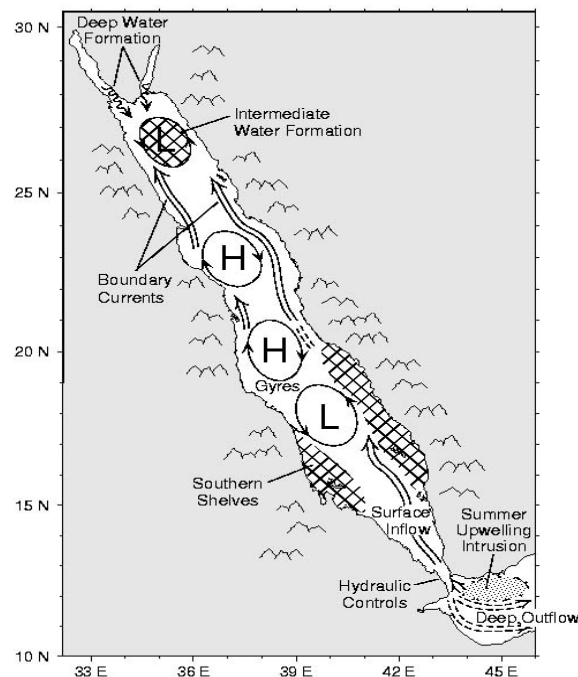
Red Sea and Persian Gulf

A long, narrow marginal sea centered at about 38 °E and 22 °N which separates the African and Asian continents. Its total length is 1932 km and the average width 280 km, with a maximum width of 306 km and a minimum width of 26 km. The area is about 450,000 km² and the volume around 50,000 km³. The average depth is about 491 m with the greatest depths over 2500 m in the trough between 19 and 22° N. The Sinai Peninsula divides the northern part into the shallow Gulf of Suez to the west and the deep Gulf of Aquaba to the east. The southern limit, which separates it from the Gulf of Aden, is a line joining Husn Murad and Ras Siyan.

The Red Sea (see Ross in Ketchuin, 1983) is a rift valley, resulting from the separation of Africa and the Arabian Peninsula, which is essentially closed at the north (except for the Suez Canal) and opens to the Gulf of Aden, Arabian Sea and the Indian Ocean at the south through the narrow strait of the Bab al Mandab. The depth averages 560 m with maximum values of 2,900 m and a sill of about 110 m depth at the Bab al Mandab in the south. The major feature of the region is the high rate of evaporation of some 200 cm/year while precipitation averages about 7 cm/year and there are no rivers flowing into the Sea. The water structure consists of a shallow upper layer and the main deep water separated by a thermocline/halocline at about 200 m depth. The temperature in summer (June -

September) at the surface is 26°-30°C and in winter (October - May) is 24°-28°C while below the thermocline the deep layer is nearly isothermal at 21.60°-21.8 °C. The Red Sea is the most saline large body of ocean water with surface layer values of 38 - 40 psu in summer and winter (although higher values to 42.5 psu occur in the north) and deep water values of 40.5-40.6 psu. The deep water is formed by winter cooling in the north. The surface layer is saturated with dissolved oxygen but the absolute values are low because of the high temperatures and salinities, i.e. less than 4mL/L. There is an oxygen minimum of 0.5-1.5 mL/L at 400 m below the thermocline/halocline while the deep water below this has a content of about 2 mL/L.

The circulation has a seasonal variation related to the winds. In summer (South-west Monsoon) the winds are to the south over the whole Sea and the surface flow is southward with outflow through the Bab al Mandab, while there is a subsurface inflow to the north through that strait. In the winter (North-east Monsoon) the winds over the southern half of the Sea change to the north and there is a northward surface flow over the whole of the Red Sea and a subsurface southward flow with outflow through the Babal Mandab. The outflow here is from an intermediate layer to about 100 m depth and this water can be traced through the Arabian Sea and down the west side of the Indian Ocean to 25°S at about 600 m depth. The residence time for the upper layer has been estimated at 6 years and for the deep water at 200 years.



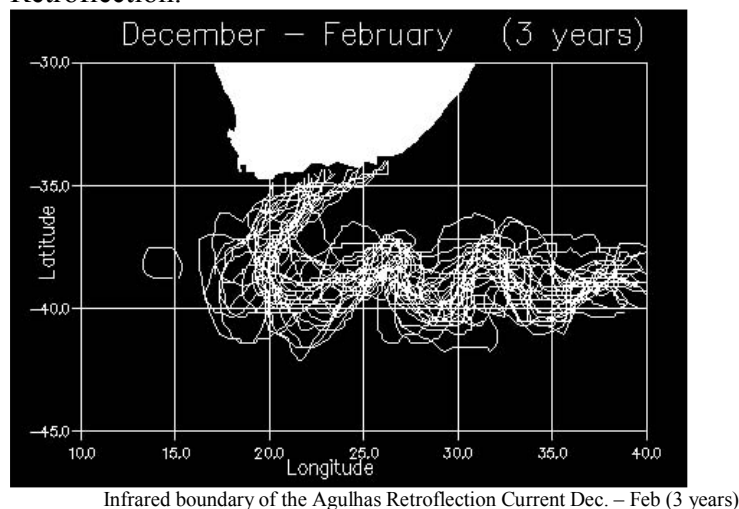
The circulation is composed of a series of high a low circulation cells. The central Red Sea is dominated by two highs while lows are at the top and bottom of the Sea. The low at the north end is a site of intermediate water formation. At the

southern end there are fairly large shelf regions which are missing in the north. All of the boundary currents flow to the north.

Notable features of the Red Sea are the hot brine pools found in some of the deepest parts (e.g. see Degens and Ross, Eds., 1969). Temperatures of 58 °C and salinities of 320 psu have been recorded, although this latter figure is not directly comparable to ocean water salinities as the chemical constitution of these brines is very different. They have a much higher content of metal ions. (For comparison, a saturated solution of sodium chloride in water has salinity in the oceanographic sense of about 270.). Various explanations have been offered for the origin of these brine pools. The one with the fewest arguments against it is that this is interstitial water from sediments, or solutions in water of crystallization from solid materials in the sea bottom, released by heating from below and forced out through cracks into the deep basins of the Red Sea. In this connection it should be noted that the Red Sea is one of the two places where a mid-ocean ridge runs into a continent, and it is a region where the heat flow up through the bottom is much greater than the world average of $4 \times 10^{-2} \text{ W/m}^2$. In contrast to the Red Sea, the Persian Gulf has a mean depth of only 25 m. Water of temperature between 15° and 35°C and salinity up to 42 psu is formed here and some is contributed to the Arabian Sea.

Retroflection

In oceanography, this refers to a geographical looping of a current away from its original direction to a substantially different direction. For example Agulhas Retroflection.



Ridge

A long, narrow elevation of the sea floor with steep sides and irregular topography.

Roaring forties

The region between 40 and 50 °S latitude where the prevailing westerly winds blow largely unobstructed by land over the open oceans, and also the winds themselves. They are constant and of great velocity, whence comes the term "roaring". The weather is stormy, rainy, and comparatively mild in the wake of constantly appearing depressions. The land areas that do obstruct them, the western mountainous coasts of southern Chile, Tasmania and New Zealand, experience tremendous rainfall through the year on the western sides (up to 100 in.) and much less on the eastern sides (around 20 in.). These are also known as brave west winds.

Rossby wave

Large scale waves in the ocean or atmosphere whose restoring force is the β -effect of latitudinal variation of the local vertical component of the earth's angular rotation vector, i.e. the Coriolis force. In the atmosphere they are easily observed as the large-scale meanders of the mid-latitude jet stream that are responsible for prevailing seasonal (via blocking) and day-to-day weather patterns. They are more difficult to detect in the ocean as their sea surface height signature is on the order of 10 cm, their propagation speeds of order 10 cm/s, and their wavelengths hundreds to thousands of kilometers.

Rossby waves in the ocean are responsible for establishing the westward intensification of circulation gyres, the Gulf Stream being one example of this. They are also the dynamic mechanism for the transient adjustment of the ocean to changes in large-scale atmospheric forcing, e.g. information is transmitted from the tropical oceans to mid- and high-latitudes via Rossby waves acting in concert with coastal trapped waves. They are generated by wind and buoyancy forcing at the eastern boundaries and over the ocean interior. They are also known to be generated by perturbations along the eastern boundaries caused by coastal trapped waves originating at low latitudes. They subsequently freely propagate away from their source regions.

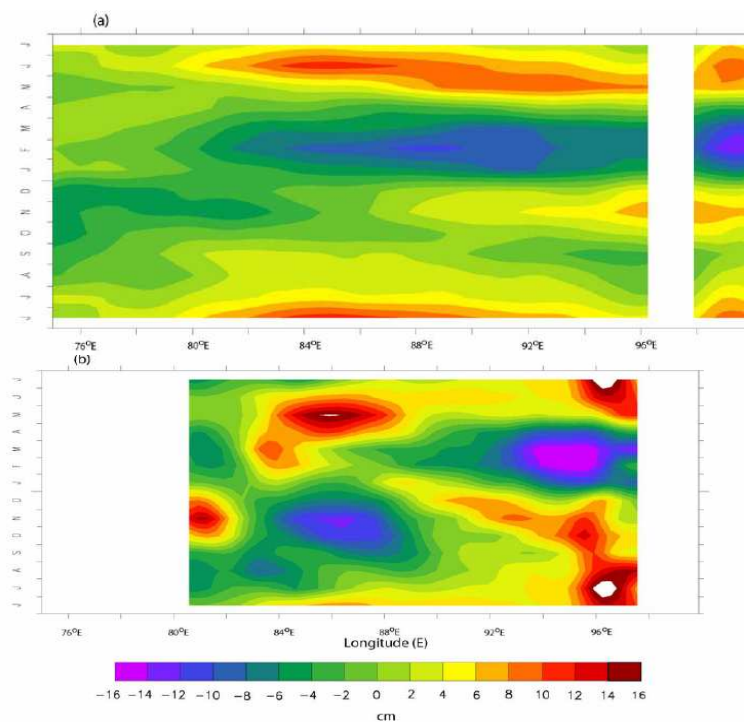
Standard theory derives the properties of freely propagating Rossby waves from the linearized equations of motion for large-scale, low-frequency motion about a state of rest, which yields an equation for normal modes. These normal modes can be found by specifying surface and bottom boundary conditions and solving an eigenvalue problem that depends only on the local stratification. There are an infinite number of wave modes ordered by decreasing phase speed, which are westward for all modes. Solutions for low frequencies and long wavelengths are zonally nondispersive, i.e. the phase speed is independent of the wavelength.

The lowest mode is the barotropic mode. It is uniform vertically and propagates across an ocean basin in about a week. The next gravest, or first baroclinic, mode is surface intensified, depends strongly on the stratification profile, has a velocity profile that changes sign at the depth of the thermocline, and takes months to cross the same basin as the first mode does in a week. The surface height variations of this mode are mirrored as thermocline depth variations of the

opposite sign, which are also about three orders of magnitude larger, i.e. a 5 cm surface elevation variation would correspond to a 50 m depression in the thermocline.

Rossby wave propagation in Bay of Bengal

The figure shows the plot of monthly mean sea level anomaly climatology derived from merged sea level anomalies of Topex/Poseidon and ERS 1/2 satellites along 4°N (a) and 16°N (b). The time-longitude plot along 4°N showed bands of alternate positive and negative sea level anomaly. These are the signatures of westward propagating Rossby waves with positive sea-level anomaly during summer and negative during winter. In summer the central and eastern region showed the highest positive sea-level height anomaly as shown in (a) and this again contributed to the observed deep MLD in the southern Bay in addition to the reduction in stratification due to the intrusion of high salinity waters from the Arabian Sea. The sloping contours in Fig. (b) indicated the signatures of the westward propagating Rossby waves.



Salinity

An oceanographic concept conceived to provide a measure of the mass of salt per unit mass of seawater. The first systematic attempt to define this was made by a commission appointed by the International Council for the Exploration of the Sea

in 1899 and chaired by Knudsen. Attempts to measure salt content by drying samples were accompanied by losses of volatile compounds along with the water, and the hygroscopic nature of the residue also served to complicate matters. A dry residue method where the sample was evaporated and dried to a stable weight at 480° C after processing with hydrochloric acid was offered as an alternative method. This led to the definition of the salinity as "the total amount of solid material in grams contained in one kilogram of seawater when all the carbonate has been converted to oxide, all the bromine and iodine replaced by chlorine, and all the organic material oxidized."

When this dry residue method also provided practical difficulties aboard ship the commission defined a chlorinity that could be determined via a volumetric titration using silver nitrate. This measurement could be combined with the assumption of constant ionic ratios in seawater to obtain a measure of the salinity, with the relationship between the two quantities being defined as

$$S(‰) = 0.03 + 1.805 \text{ Cl}(‰).$$

A small adjustment was made in the definition of chlorinity in the late 1920s, but it remained basically the same until the development of reliable and precise electronic instrumentation in the 1950s led to a qualitative redefinition of the chlorinity, and therefore the salinity, in terms of measurements of the electrical conductivity of a water sample. This led to the creation and publication of the International Oceanographic Tables giving salinity as a function of conductivity ratio above 10 μ . These tables were adequate for the laboratory determination of salinity, but could not be used with in-situ salinometers since most such measurements were made at temperatures below 10 μ C. A separate set of tables were developed in the mid-1960s that covered the range 0-30 μ C, although this led to discrepancies between in-situ and bench measurements of salinities and many separate attempts to patch together the two data sets. This in turn led to confusion in the comparison of salinity data amongst the major oceanographic institutes.

A solution was found in 1978 in the form of a new definition called the Practical Salinity Scale where the practical salinity is defined in terms of the ratio of the electrical conductivity of a seawater sample at atmospheric pressure at 15 μ C to that of KCl solution containing 32.4356 g of KCl in a mass of 1 kg of solution at the same pressure and temperature. This ratio K_{15} defines practical salinity of a sample according to

$$S(‰) = a_0 + a_1 K_{15}^{1/2} + a_2 K_{15} + a_3 K_{15}^{3/2} + a_4 K_{15}^2 + a_5 K_{15}^{5/2}$$

where $a_0 = 0.0080$, $a_1 = -0.1692$, $a_2 = 25.3851$, $a_3 = 14.0941$, $a_4 = -7.0261$, and $a_5 = 2.7081$. This definition suffices for laboratory determination of salinity for samples at the aforementioned pressure and temperature, but corrections must be made for in-situ measurements in water of salinity S and temperature T . These are available in the form of additional tables and equations.

Sandstrom Theorem

An ocean circulation theorem that states that a closed steady circulation can only be maintained in the ocean if the heat source is situated at a lower level than the cold source.

Scattering

The process by which some of a stream of radiation is dispersed to travel in directions other than that which from it was incident by particles suspended in the medium through which it is travelling.

SCOR

Acronym for Scientific Committee on Oceanic Research, an ICSU committee.

Seasonal thermocline

In oceanography, a weakly stratified layer of water that appears when the mixed layer makes a rapid transition between its winter maximum and its summer minimum. It is created by deep convection during the winter, and several processes are responsible for its restratification during the rest of the year. These processes, in chronological order starting in early spring, are the creations of a fossil thermocline during the ascent of the mixed layer, solar heating below the mixed layer, geostrophic advection, and thermohaline intrusion.

Seamount

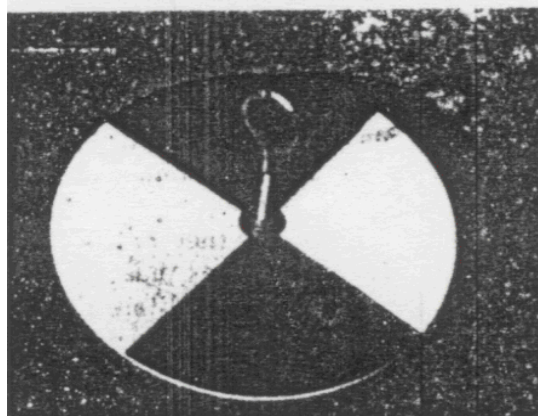
An isolated or comparatively isolated elevation rising 1000 m or more from the sea floor and of limited extent across the summit. Tens of thousands of isolated peaks, *seamounts*, are scattered throughout the ocean basins. They interrupt ocean currents, and produce turbulence leading to vertical mixing of water in the ocean.

SeaWiFS

Acronym for Sea-viewing Wide-Field of view Sensor, an ocean color sensor to study ocean productivity and interactions between the ocean ecosystems and the atmosphere.

Secchi disk

A round, black and white disc with a diameter of around 0.25 m that is lowered from a vessel and viewed from above the surface in full solar illumination to estimate the attenuation of light in the water column. This is done by empirically relating the depth at which the disk disappears to the attenuation. This method was devised in the 1860s by an Italian astronomer named Angelo Secchi who used it while he worked in the Mediterranean aboard the papal vessel *Immacolata*.



Sensible heat (Q_H)

The portion of total heat associated with a temperature change, as opposed to latent heat. This is so-called because it can be sensed by humans. This is also called outgoing long wave radiation. The sensible heat is calculated by

$$\Delta Q = m C_p \Delta T$$

where C_p values are

$$C_{pd} = 1004.67 \text{ J kg}^{-1} \text{K}^{-1}$$

for dry air,

$$C_p = C_{pd} (1 + 0.84 r)$$

for moist air (where r is the mixing ratio of water vapor), and

$$C_{liq} = 4200 \text{ J kg}^{-1} \text{K}^{-1}$$

for liquid water.

Sensible heat flux

The flux of heat between the ocean surface and atmosphere that results mainly from their difference in temperature. The heat exchange is accomplished via molecular conduction in the first few millimeters above the surface and via turbulent mixing and convection above that. The flux is usually from the ocean to the atmosphere during the day and opposite during the evening and night.

Shallow scattering layer

A layer of marine organisms found over a continental shelf which scatter sound. These layers are usually composed of patchy and horizontally discontinuous

groups whose horizontal dimensions are usually less than their vertical dimensions. There are also surface and deep scattering layers.

Shelf sea

A shallow sea that occupies a portion of a wide continental shelf. This is one type of epicontinental sea. Compare to epeiric sea and inland sea.

SI Unit

Abbreviation for Systeme Internationale.

Sidereal day

The interval of time between successive passages of the vernal equinox across the same meridian. It is 23 h, 56 m, 4.091 s of mean solar time. The sidereal day is defined to begin at sidereal noon. The time it takes for the Earth to rotate once relative to the stars is longer than the sidereal day by about 0.008 s due to the effect of the precession of the equinoxes.

Sidereal time

Time measured by considering the rotation of the Earth relative to the distant stars (as opposed to civil time relative to the Sun). The sidereal time at any instant is the same as the right ascension of objects exactly on the meridian.

Sigma-t

A conventional definition introduced into physical oceanography for purposes of brevity. It is the remainder of subtracting 1000 kg m⁻³ from the density of a sea water sample at atmospheric pressure, i.e.

$$\sigma_t = (\rho_{S,T,0} - 1000),$$

where S and T are the in situ salinity and temperature. The density of water ranges from 1000 kg/m³ to about 1028 kg m⁻³ for the densest ocean surface water, so sigma-t ranges from about 0.00 to 28.00, with the units usually omitted.

Sigma- θ

A measure of the density of ocean water where the quantity sigma-t is calculated using the potential temperature θ rather than the *in situ* temperature, i.e.

$$\sigma_\theta = (\rho_{S,\theta,0} - 1000),$$

where S is the in situ temperature.

Sill

The lower part of the *ridge* separating ocean *basins* from one another or from the adjacent sea floor. The subsea features have important influences on the ocean circulation. Ridges separate deep waters of the oceans into distinct *basins* separated by *sills*. Water deeper than a sill cannot move from one basin to another. A sill generally will be convex shape at the bottom of the basin. For example, Zibralter sill.

Skin effect

A temperature inversion in a thin near-surface ocean layer with a thickness of several millimeters. This is a source of uncertainty in radiometric measurements. The inversion layer, created mainly by evaporation, results in an underestimation of the SST compared with what it would be as determined by conventional methods in a layer with a thickness ranging from several tens of centimeters to several meters.

Snell's law

A law that gives the relationship between the incident and refracted angles at an interface between two media. It is expressed as

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{c_1}{c_2} = \frac{n_2}{n_1}$$

where θ_1 and θ_2 are the incident and reflected angles, respectively, c_i the speed of light through medium i , and n_i the refractive index for medium $i=1$ or 2 .

SOFAR

Acronym for SOund Fixing And Ranging floats, subsurface floats used since the mid 1970s that freely drift at prescribed pressures. These provide direct measurements of the ocean circulation by sending acoustic pulses, typically at 300 MHz, once a day which can be used to calculate their positions from their Times of Arrivals (TOAs) at listening stations moored near the SOFAR channel depth at known geographical positions.

Solar constant

The energy flux density of the solar luminosity at a given distance from the Sun. At the mean distance of the Earth from the Sun the most probable value of this flux is in the range from 1368 to 1377 Wm^{-2} .

It is defined as amount of solar energy falls in a minute on a unit surface placed normal to the rays in the mean distance between sun and earth. It is roughly equal to 2.0 langleys/minute.

Solar declinational angle

The angle between the ecliptic and the plane of the earth's equator. This varies from $+23.45^\circ$ on June 22 to -23.45° on Dec. 22 corresponding to, respectively, summer and winter solstice in the northern hemisphere. The solar declination angle for any day of the year is given by

$$\delta_s = \phi_r \cos \left[\frac{C(d - d_r)}{d_y} \right]$$

where ϕ_r is the tilt of the earth's axis relative to the ecliptic, d is the Julian Day of the year, d_r is the Julian Day of the summer solstice (i.e. 173), d_y is the number of days per year, and C is the circle circumference (i.e. 360°).

Somali Current

A prominent western boundary current in the northern Indian Ocean.

During the northeast monsoon season the Somali Current flows southward from 5° to 1°N in December, expanding to 10°N–4°S in January–February and contracting again to 4°N–1°S in March. It is then fed from the North Equatorial Current and discharges into the Equatorial Countercurrent. During all these months its speed is 0.7–1.0 m s⁻¹. During the southwest monsoon the current develops into an intense northward jet with extreme surface speeds; 2 m s⁻¹ have been reported for May and 3.5 m s⁻¹ for June. The jet is fed from the South Equatorial Current and flows along the eastern coast of the Horn of Africa; part of it continues along the Arabian Peninsula as the East Arabian Current. South of 5°N the jet is shallow; southward flow continues below a depth of 150 m. North of 5°N the jet deepens and embraces the permanent thermocline. During its northward phase the Somali Current is associated with strong upwelling between 2° and 10°N. The upwelled cold water turns offshore near Ras Hafun (11°N), forming a large anticyclonic eddy with a diameter of about 500 km known as the Great Whirl. Eventually the water from the Somali Current enters the southwest Monsoon Current.

Somali Current Large Marine Ecosystem (SCLME)

The SCLME lies off the northeastern margin of the African continent and includes the continental shelf areas of Yemen, Somalia, Kenya and Tanzania. It is a monsoon-influenced Indian Ocean ecosystem and is characterised by a tropical climate. In summer, the strong Somali Current flows in a northerly direction. In winter, it reverses its flow. The coastal waters of the SCLME are home to many diverse plants and animals that are endemic to the region.

However, the environmental integrity of the Somali Current LME has been severely impacted by the effects of human population growth, intensification of land use and damaging fishing methods.

The oceanographic conditions in the Agulhas and Somali Current LMEs (ASLME) are distinct. In the southern part of the West Indian Ocean, the Agulhas Current system dominates. This current is one of the largest western boundary currents in the world and is fed from a range of complex sources. By contrast, the Somali Current in the northern part of the West Indian Ocean, is a shallow current that has the unusual characteristic of seasonally reversing direction. In addition, there are currents that carry water past the islands of the south West Indian Ocean and which form part of the typical wind-driven subtropical gyre.

Knowledge of the oceanography of these different systems, including their physical, chemical, biological and geological features, is highly variable. Parts of the Agulhas Current system have been comprehensively studied, but knowledge about other parts – the Mozambique Channel and the seas around Madagascar, for instance – is scant. And, while some features of the Somali Current have been relatively well observed in the past, no studies are taking place inshore because of security concerns in Somalia. In addition, few dedicated oceanographic studies have been undertaken in the vicinity of

most of the islands of the south West Indian Ocean. The influence of all these currents on the circulation over the adjacent shelves, the local chemistry, biology and sediment movement has been inadequately investigated.

This summary of what is known about the oceanography of the West Indian Ocean is strongly skewed towards physical oceanography. Considerably less is known about the chemical oceanography, biological oceanography and marine geology of the region.



Some countries have little or no support for marine resource management, while others, such as the Seychelles, South Africa, Kenya, Tanzania and Madagascar, have been able to establish marine protected areas or are attempting to improve current management practices. Many organizations are working to improve scientific knowledge and understanding of the marine resources, develop regional cooperation between countries, promote sustainable practices, and protect the substantial biodiversity of the Western Indian Ocean region

South Equatorial Countercurrent

An eastward current in the Atlantic and Pacific that flows between 5 and 10° S., the limited evidence for which shows it to be much less well developed than the North Equatorial Countercurrent (NECC). In the Indian Ocean the SECC is almost totally confined between the equator and the northern boundary of the South Equatorial Current (SEC) at 4° S.

South Equatorial Current

A westward flow in the Atlantic and Pacific located south of the North Equatorial Countercurrent (NECC) generally below 5° N. It flows between about 3° N and 10° in the Pacific with speeds estimated at around 50 to 65 cm s⁻¹ and an average mean transport of 17 sv, although this latter quantity annually varies by about 10 sv about the mean. The SEC is strongest during July and August and usually vanishes during the northern winter and spring. This is also seen in the Indian Ocean south of 4° S.

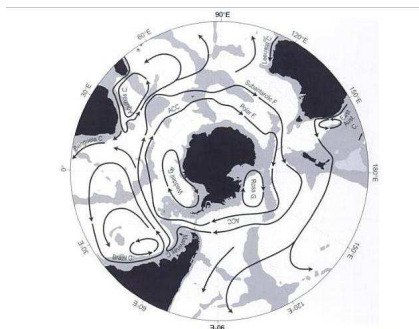
South Equatorial Undercurrent

An eastward flow in the Atlantic Ocean whose core is located near 200 m depth a few degrees south of the Equator. A satisfactory dynamical explanation for this is as yet nonexistent.

Southern Ocean

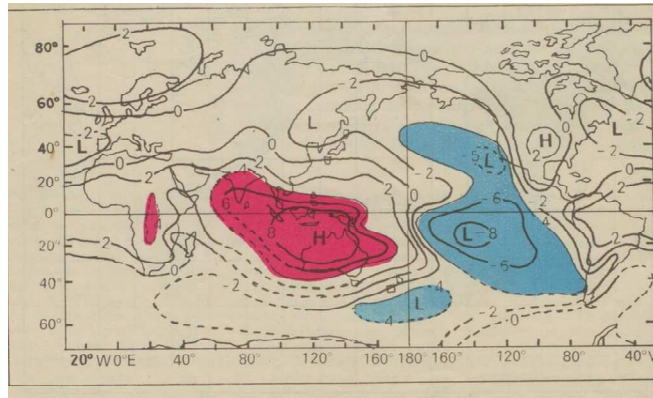
In oceanography, an unofficial term used to describe the oceans surrounding the continent of Antarctica. The northern limit is the broad zone of transition where the permanent thermocline reaches the surface at the Subtropical Convergence (STC). The southern limit is similarly demarcated by the Subtropical Front. It is distinguished from the other oceans by the relative uniformity of its characteristics of hydrography and circulation and that it influences more than it is influenced by the others.

The Southern Ocean bathymetry consists of three major basins where the depth exceeds 4000 m separated by three major ridges that reach at least to the 3000 m level. These are (proceeding from the Pacific sector west): (1) the Amundsen, Bellingshausen, and Mornington Abyssal Plains, sometimes called the Pacific-Antarctic Basin, (2) the Macquarie, Pacific-Antarctic, and Southeast Indian Ridge sytem, (3) the Australian-Antarctic Basin, (4) the Kerguelan Plateau, (5) the Ender and Weddell Abyssal Plains, also known as the Atlantic-Indian Basin, and (6) the Scotia Ridge.



Southern Oscillation

The name given to the atmospheric component of the El Nino/Southern Oscillation (or ENSO) phenomenon. The SO is a large-scale shift in atmospheric mass between the western and eastern Pacific, monitored by computing the SOI. An SOI indicating El Nino conditions means that there is reduced rainfall over the Indonesian region and that the west Pacific convective center is displaced eastward along the equator.



Southern Oscillation Index

An index that is calculated to monitor the ENSO phenomenon. It is defined as the pressure anomaly at Tahiti minus the pressure anomaly at Darwin, Australia. Anomalously high pressure at Darwin and low pressure at Tahiti are indicative of El Nino conditions.

(a) Positive SOI:	(i) Tahiti pressure greater than Port Darwin. (ii) Pressures high over east Pacific and low over Indian Ocean. (iii) Low rainfall over eastern Pacific and prospects of good monsoon rain over India and Indian Ocean.
(b) Negative SOI:	(i) Port Darwin pressure exceeds Tahiti. (ii) Pressures high over Indian Ocean and low over eastern Pacific. (iii) Low rainfall or poor monsoon over Indian Ocean and higher than usual rain over east Pacific.

Specific heat

A thermodynamic quantity indicating the rate of change of heat content with temperature. More specifically, this is the heat required to raise the temperature of a unit mass of a given substance by one degree. It is normally expressed in units of calories/gm °K. The specific heat of water is 1.00 cal/gm °K (although this varies about 1% with temperature), and the specific heat of dry air at constant pressure (C_p) is 0.240 cal/gm °K and at constant volume (C_v) 0.171 cal/gm °K. For water vapor the constant pressure (C_p) value is 0.441 and the constant volume (C_v) value 0.331 cal/gm °K.

Specific volume

The reciprocal of density. In the determination of the specific volume of sea water, the specific volume $\alpha_{S,T,P}$ is expressed as

$$\alpha_{S,T,P} = \alpha_{35,0,P} + \delta_S + \delta_T + \delta_{S,T} + \delta_{S,P} + \delta_{T,P} + \delta_{S,T,P}$$

where the second through seventh terms on the right-hand-side are called the specific volume anomaly and the second through fourth terms the thermosteric anomaly.

Specific volume anomaly

A physical oceanographic term referring to that portion of the specific volume differing from a standard specific volume determined at a salinity of 35 ppt, a temperature of 0 °C, and the pressure at the depth at which the sample was taken.

Stability

In physical oceanography, a measure of the tendency of a water parcel or particle to move vertically in comparison with its surroundings. Neglecting adiabatic effects, the stability is defined (over short vertical distances) by

$$E = \frac{1}{\rho} \frac{d\rho}{dz}$$

where ρ is the density and z the vertical coordinate. There is a correspondingly more complicated expression for the stability when adiabatic effects are taken into account as is usually necessary at great depths. Typical values of E in the upper 1000 m range from 100 to $1000 \times 10^{-6}/\text{m}$, with the largest values generally occurring in the upper few hundred meters. Below 1000 m values decrease to less than $100 \times 10^{-6}/\text{m}$ and can get as small as a hundredth of that in deep trenches.

Steric height

In oceanography, a quantity introduced to determine the distance or depth difference between two surfaces of constant pressure. The steric height h is defined by

$$h(z_1, z_2) = \int_{z_1}^{z_2} \delta(T, S, p) \rho_0 dz$$

where z_1 and z_2 are the depths of the pressure surfaces, δ the specific volume anomaly, T the temperature, S the salinity, p the pressure, and ρ_0 a reference density. It has the dimension of height and is expressed in meters.

Stommel, Henry Melson (1920-1992)

A physical oceanographer who has been called "the most significant scientific contributor to the development of oceanography", Stommel's long and distinguished career was marked not only by many significant scientific contributions to his field but also by his unsurpassed ability to help others in their research efforts and to catalyze the development of major research programs.

His scientific contributions included proposing the use of T-S correlations to estimate missing salinity values from measured temperatures in order to calculate dynamic heights, the beta spiral method for determining absolute geostrophic circulation fields, the initiation of studies of double diffusion, and the development in the early 1960s (along with Arnold Arons) of a model of abyssal circulation that still serves as the fundamental basis for further investigations today. His most famous contribution was his 1947 paper in which he developed an analytical model showing how the westward intensification of ocean currents

is caused by the variation of the Coriolis parameter with latitude (i.e. the beta effect).

His efforts to foster research programs included the genesis of the long-term measurements of the deep waters off Bermuda in 1953, the planning (with K. Yoshida) of a survey of the Kuroshio Current in the late 1960s, the proposal of a dense network of oceanographic stations off the coast of Bermuda that resulted in the Mid-Ocean Dynamics Experiment (MODE), and the motivation of the geochemistry community to carry out the GEOSECS program.

His work led to hundreds of publications under his name and with dozens of collaborators, and given his generosity in sharing his original ideas and experiences with others hundreds more thanking him in the credits. His books included *Science of the Seven Seas* (1945), *The Gulf Stream* (1966), *Kuroshio* (co-edited with K. Yoshida in 1972), *Volcano Weather* (co-written with his wife Elizabeth in 1983), *Lost Islands* (1984), *A View of the Sea* (1987) and *Introduction to the Coriolis Force* (co-written with Dennis Moore in 1989). He inspired the 1981 festschrift entitled *Evolution of Physical Oceanography: Scientific Surveys in Honor of Henry Stommel* (edited by B. Warren and C. Wunsch). The *Collected Works of Henry M. Stommel* (edited by N. Hogg and R. Huang) were published in three volumes in 1995. This set includes introductory essays for each chapter written by his many colleagues as well as previously unpublished material, e.g. about a hundred pages from his unpublished autobiography.

Stommel-Arons thermohaline circulation

A model of global thermohaline circulation developed by Henry Stommel and Arnold Arons in a series of papers starting in 1961. This model combines sources of abyssal water at either pole, the turbulent mixing of warm surface water downward, the broad and slow upward flow of cold deep water, and deep western boundary currents in a dynamically consistent manner to provide a first-order explanation for that part of the general ocean circulation driven by spatial differences in the salinity, temperature and, therefore, density of sea water.

Straits of Gibraltar

A shallow strait that separates the eastern Atlantic Ocean from the Mediterranean Sea.

Stratification

In oceanography, the vertical density structure resulting from a balance among atmospheric heating, surface water exchange, freezing, stirring and diffusion of heat, and the horizontal and vertical motion (advection) of waters with different temperature and salinity characteristics.

Stratification is a measure of how much the density of the water changes with depth. More highly stratified water has a greater change of density with depth. The term stratification may also be used to apply to vertical gradients of

temperature, salinity, or other variables if so stated. The part of the water column where the change of temperature with depth is the greatest is called the thermocline, similarly for the halocline but with reference to salt, and pycnocline for density

Subantarctic Front

In physical oceanography, a region of rapid transition in the Southern Ocean between the Polar Frontal Zone (PFZ) to the south and the Subantarctic Zone (SAZ) to the north. Its position is generally identified by the rapid northward sinking of the salinity minimum associated with the Antarctic Intermediate Water (AAIW) from near the surface in the PFZ ($S < 34$) to depths greater than 400 m in the SAZ ($S < 34.30$). The property indicators within the front are $S < 34.20$ at $Z < 300$ m, $\theta > 4-5^\circ$ at 400 m, and $O_2 > 7$ ml/l at $Z < 200$ m. The SAF is one of three distinct fronts in the Antarctic Circumpolar Current (ACC), the others being (to the south) the Polar Front (PF) and the Southern ACC Front (SACCF).

Subantarctic Mode Water

In physical oceanography, a type of water in the Subantarctic Zone of the Southern Ocean. The SMW is the deep surface layer of water with uniform temperature and salinity created by convective processes in the winter. It can be identified by a temperature of around -1.8°C and a salinity of around 34.4 and is separated from the overlying surface water by a halocline at around 50 m in the summer. Although it is not considered to be a water mass, it contributes to the Central Water of the southern hemisphere, and is additionally responsible for the formation of AAIW in the eastern part of the South Pacific Ocean. This has also previously been called Winter Water.

Subantarctic Upper Water

In physical oceanography, a water mass located in the Subantarctic Zone of the Southern Ocean. It is characterized hydrographically by temperatures ranging from $4-10^\circ\text{C}$ in the winter and $4-14^\circ\text{C}$ in summer, with salinities between 33.9 and 34.9 and reaching as low as 33.0 in the summer as the ice melts.

Subantarctic Zone

The name given to the region in the Southern Ocean between the Subantarctic Front to the south and the Subtropical Front to the north. This zone is characterized by the presence of SAUW at and near the surface. The SAZ is one of four distinct surface water mass regimes in the Southern Ocean, the others being (to the south) the Polar Frontal Zone (PFZ), the Antarctic Zone (AZ) and the Continental Zone (CZ).

Subduction

An important feature of the upper ocean subtropical circulation, called subduction, is associated with the density structure of the ocean, in which density increases with depth. When the warm equatorial surface water flows poleward in the western boundary current, it is subjected to intense cooling. This cooler water circulates back towards the south. On encountering the warmer water in the south, this cooler water submerges beneath the lighter surface waters. This process occurs for all waters that enter the subtropical gyres. This submerging process was named as subduction by Luyten et al (1983) who were the first to fully describe the process and provide a theory for it.

Subtropical Convergence

The name given by Deacon (1937)) to the hydrographic boundary between the Southern ocean and subtropical waters to the north. This was replaced by the term Subtropical Front (STF) in the mid-1980s.

Subtropical Front

In physical oceanography, a region of pronounced meridional gradients in surface properties that serves as the boundary between the Southern Ocean and the waters of the subtropical regime to the north. This was originally called the Subtropical Convergence (STC) by Deacon but the newer terminology arose in the mid-1980s. This is generally a subduction region for various types of Central Waters.

The STF separates the Subantarctic Surface Water (SASW) to the south from the Subtropical Surface Water to the north. The surface hydrographic properties of the STF include a rapid salinity change from 35.0 to 34.5 and a strong temperature gradient (from 14-10° C in winter and 18-14° C in summer) as one crosses from north to south. At 100 m its approximate location is within a band across which temperatures increase northward from 10 to 12° C and salinities from 34.6 to 35.0, with the salinity gradient usually the more reliable indicator. The position as well as the intensity of sinking or rising motion in the STF is more variable than in any other front or divergence in the Southern Ocean.

Subtropical gyre

A clockwise/counterclockwise circulation in the northern/southern hemisphere that is forced by the wind and features western intensification in the form of a western boundary current. In the northern hemisphere the gyres span the width of the oceans and extend from about 10 to 40° N with the boundary currents in the Atlantic and Pacific called, respectively, the Gulf Stream and the Kuroshio. There are analogous features in the southern hemisphere. The polar boundaries between these and the subpolar gyres coincide with the latitude at which the curl of the wind stress vanishes, the latter being largely the mechanism of causation.

Subtropics

Generally the part of the Earth's surface between the tropics and the temperate regions, or between about 40° N and S.

Surface scattering layer

A group of marine organisms in the surface layers of the ocean which scatters sound. The layer may extend from the surface to depths as great as 600 feet, and several layers or patches may comprise the layer. There are also shallow and deep scattering layers.

Sverdrup, Harald Ulrik (1888-1957)

Sverdrup started his scientific career by enrolling as a student in "physical oceanography and astronomy" at the University of Oslo, where his early interests leaned towards the latter. This changed when he received an assistantship to study under Professor V. Bjerknes, under whom he published twenty papers and a dissertation entitled *Der nordatlantische Passat* (in which he calculated energy and momentum budgets for the North Atlantic trade winds) over the next six years.

He took charge of scientific work on Roald Amundsen's North Polar expedition at the age of 29 in 1918. He did not return until late in 1925 as the expedition ship *Maud* attempted to duplicate the voyage (and ice drift) of the *Fram*. At one point during the seven years of this expedition Sverdrup left the ship to spend eight months with the nomadic Chukchi tribe of northeastern Siberia, an experience he later recounted in a book (which has never been translated into English). The collected observations of the expedition were a notable achievement, with Sverdrup's most significant contribution being a paper entitled "Dynamics of tides on the North Siberian Shelf."

Sverdrup succeeded V. Bjerknes as the Chair of Meteorology at the Geophysical Institute in Bergen, Norway upon his return, and he additionally became a research professor at the Christian Michelson Institute in Bergen in 1931. The ten years following his return from the *Maud* expedition were the most productive of his career, with his accomplishments including publishing over fifty papers on results from the expedition, spending two half-year periods in Washington, D.C. to help analyze the results from a cruise of the *Carnegie*, taking charge of the scientific work on the Wilkins Ellsworth North Polar Expedition aboard the submarine *Nautilus* in 1931, and spending two months in the snow fields of Spitzbergen which resulted in the first quantitative heat budget of glaciers.

In 1936 he accepted the Directorship of the Scripps Institution of Oceanography in La Jolla, California, leaving the Michelson Institute for three years, although the war resulted in his not returning to Norway until 1948. At Scripps Sverdrup initiated the Marine Life Research Program (still ongoing today), organized the first systematic course in oceanography given in the United States, and taught and collaborated such future renowned scientists as Gifford Ewing, Donald Pritchard, Roger Revelle, Robert Reid and Walter Munk. He spent a great deal of

time and effort during the pre-war years collaborating with Martin Johnson and Richard Fleming to write the classic text *The Oceans*, with his chapter on the water masses and currents of the oceans still one of the best reviews of the subject available.

He returned to Norway in 1948 at the age of sixty and retired from research, dividing his time variously as Director of the Norsk Polar Institut, the President of the ICES, Prorector and Director of the Summer School for foreign students at the University of Oslo, and as Chairman of a committee for reorganizing the Norwegian educational system. He continued in these activities until a stroke weakened him and led to his death in 1957.

Sverdrup (Sv)

A unit of transport used in oceanography equivalent to $10^6 \text{m}^3 \text{s}^{-1}$ (one million cubic meters per second) and abbreviated as Sv.

Swash zone

The portion of the nearshore zone in which the beach face is alternately covered by the uprush of wave swash and exposed by the backwash.

Synodic

Descriptive of the period between successive conjunctions of two objects. The synodic period of a planet or a moon is the interval of time between successive conjunctions of the body and the sun, as viewed from the earth.

Synoptic

Description of data simultaneously obtained over a large area.

Temperate

Description of a climate in which the temperatures are moderate or mild, or of any climate in middle latitudes.

Thermal equator

An imaginary line connecting those points around the globe with the highest mean temperature for the given period. As such, the position of the thermal equator varies with the season. Due to the thermal inertia of the ocean, the position of this moves north and south with the Sun but is always between the Sun and the geographic equator. The mean position is north of the geographic equator due mainly to the majority of land masses being in the northern hemisphere.

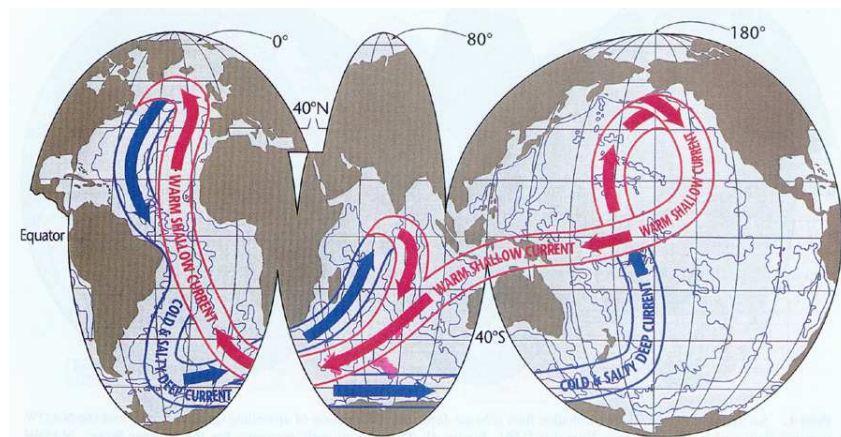
Thermocline

Specifically the depth at which the temperature gradient is a maximum. Generally a layer of water with a more intensive vertical gradient in temperature than in the layers either above or below it. When measurements do not allow a specific depth to be pinpointed as a thermocline a depth range is specified and referred to as the thermocline zone. The depth and thickness of these layers vary with season, latitude and longitude, and local environmental conditions. In the midlatitude

The basic dynamic balance that maintains the permanent thermocline is thought to be one between the downward diffusive transport of heat and the upward convective transport of cold water from great depths.

In oceanography, descriptive of a combination of temperature and salinity effects.

That part of the ocean circulation driven by temporal and spatial differences in both the salinity and temperature of the waters that comprise the world ocean. A simplified schematic model of this circulation is the conveyor belt model. The figure below shows the global ocean circulation path ways, the conveyor belt (after Broecker and modified by E.Maier-Reimer)



A layer where the vertical change of temperature is very small and displays a local minimum.

In the determination of the specific volume of sea water, this refers to a subset of that group of factors known as the specific volume anomaly that account for most of the effects of salinities and temperatures that differ from the standard calculation levels of 35 ppt and 0° C, respectively. These three terms account for the individual effects of salinity and temperature perturbations as well as their combined effect.

It is defined as the anomaly of specific volume that would be attained if the water were changed isothermally to a standard pressure of one atmosphere.

$$\Delta_{s,t} = \delta_s + \delta_t + \delta_{s,t}$$

Montgomery and Wooster (1954) pointed out that in actual oceans the effect of the sum of the three above terms is adequate in most practical cases particularly when computing the upper layers of the oceans.

TOGA

Acronym for Tropical Ocean and Global Atmosphere program, a WCRP program.

TOPEX/Poseidon

It is a satellite mission that uses radar altimetry to make precise measurements of sea level with the primary goal of studying the global ocean circulation. ERS-1 is not as accurate an altimetric satellite as TOPEX, but it has been used for important studies nevertheless. ERS-1 has a much finer spatial resolution (3/4 by 3/4 degree) than TOPEX/Poseidon (3 by 3) and a much greater spatial coverage than its more modern counterpart. This has led ERS-1 to be used to determine tidal components that has been used to compute the SSH using TOPEX/Poseidon.

A cooperative project between the U.S. and France to develop and operate an advanced satellite system dedicated to observing the Earth's oceans. It uses radar altimetry to measure sea surface height over 90% of the world's ice-free oceans. It circles the world every 112 minutes and will gather data to 3 to 5 years. It has a 10-day repeat orbit and flies between latitudes 65 °N and S. When combined with a precise determination of the spacecraft orbit, the altimetry will yield global maps of ocean topography from which the speed and directions of ocean currents worldwide will be calculated. The TOPEX/Poseidon orbit was carefully designed to avoid aliasing the solar tides into undesirable frequencies as happens with sun-synchronous spacecraft, which allows it to serve as a global tide gauge. Other features that contribute to the precise and accurate altimetry of this instrument include a higher orbit than other spacecraft, the inclusion of a water vapor radiometer designed to collect correction information, an ionosphere insensitive altimeter, and more accurate tracking than for other missions. See the TOPEX/Poseidon website.

Trade winds

The trade winds, or tropical easterlies, are the winds which diverge from the subtropical high-pressure belts, centered at 3-40 °N and S, towards the equator, from north to east in the northern hemisphere and south to east in the southern hemisphere.

Transmittance

In radiation transfer, the fraction of incoming radiation that is transmitted into or through a medium. The sum of the absorptance and the reflectance must equal to unity.

Trophic level

In marine ecology, a single level or layer in the transfer of food or energy in a chain. There can be several levels, with distinct size gradations between levels. Organisms that obtain their food by the same number of steps from plants are said to belong to the same trophic level.

Tropical year

The interval between two successive passages of the Sun in its apparent motion through the First Point of Aries. This is the interval between two similar equinoxes or solstices and the period of the seasons. Its length is 365.242194 mean solar days.

T-S diagram

A graph showing the relationship between temperature and salinity as observed together at, for example, various depths in a water column. A T-S diagram for a given station is typically prepared by plotting a point for the temperature/salinity combinations at a range of depths and then joining them by straight lines in order of depth. The resulting line is called the T-S curve. Isopleths of constant density are often also drawn on the same diagram as a useful additional interpretation aid. In the ocean certain T-S combinations are preferred which leads to the procedure of identification via the definition of water types and water masses and their distributions.

T-S-t diagram

An extension of the T-S diagram concept to include information about the temporal evolution of the properties of ocean waters in specific areas. It is created by plotting, on a standard T-S diagram, the temperature and salinity of a given area at regular time intervals (say, monthly or quarterly values).

T-S-V diagram

An extension of the concept of a T-S diagram to display the distribution of temperature and salinity in the world ocean waters in proportion to their total volume. This is created by dividing a T-S diagram into a grid of squares with each square containing a number indicating the volume of water whose properties lie within it. A 3-D graphic of the results can also be created by replacing each number with a proportionally long vertical bar. See Montgomery (1958).

Trench

A long, narrow, and deep depression of the sea floor, with relatively steep sides.

Ultra-violet radiation

Electromagnetic radiation in the approximate wavelength band from 10 to 4000 angstroms (10e^{-7} to $4\times 10\text{e}^{-5}$ cm). This is the wavelength region just below visible radiation. Very little of the total energy contained in solar radiation is found in the ultra-violet portion of the spectrum, and even that small part is strongly absorbed in the high atmosphere. This absorption results in various photo-chemical reactions including that of ozone formation. It also results in a sharp cutoff, at about 2900 angstroms, of the solar spectrum observed at the surface of the Earth. This is felicitous for the life that dwells there given the strong chemical and

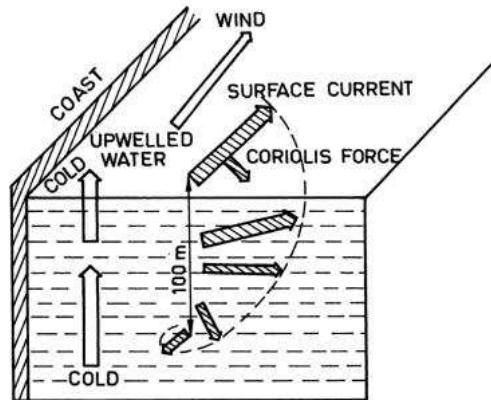
biological effects produced by ultra-violet radiation. It also explains the present concern about the depletion of ozone by chlorofluorocarbons in the stratosphere.

UTC

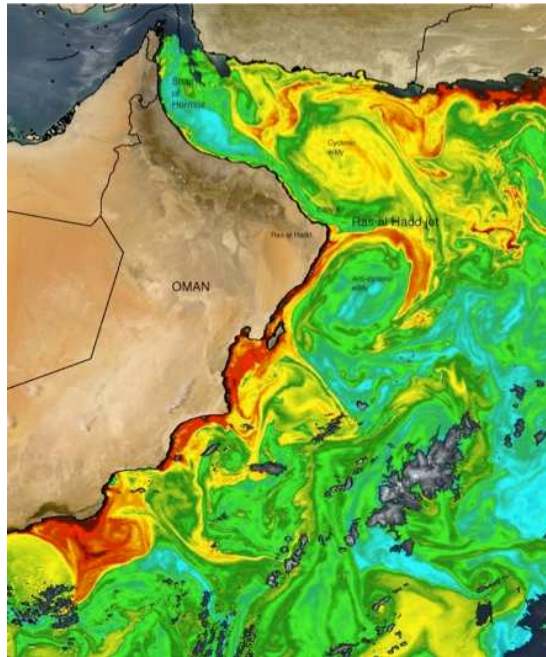
Abbreviation for Universal Time Co-ordinated. It is referred to the time at the 0° longitude. This has also been known as Greenwich Mean Time (GMT), Z Time or Zulu Time. It is the time of convention for weather reports.

Upwelling

Rising of subsurface water to the surface due to wind stress in such a way that south wind along east coast and north wind along west coast in the northern hemisphere in the case of coastal upwelling. In the case of deep ocean, upwelling a divergence caused by currents causes upwelling for example equatorial upwelling. As the Ekman net transport is normal to the coast Ekman pumping is responsible for this upwelling as shown in the figure below.



This image below shows coastal upwelling off Oman in the Arabian Sea (Northeastern Indian Ocean). The upwelled waters are traced by their high Chlorophyll-A concentrations - i.e. by strong blooms of phytoplankton. Upwelling here is seasonal, driven by southwest monsoon winds during the summer months.



Upwelling is driven by the alongshore component of the southwest monsoon winds. In response, the Ekman Layer transport is to the right of the winds, in the offshore direction, causing a divergence at the coast. Deeper waters must upwell at the coast to balance the offshore flow at the surface.

Veering

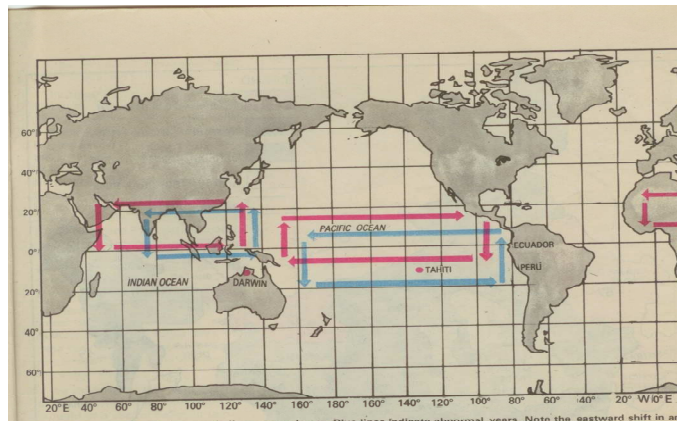
It is said as the clockwise change of the direction of a wind, as opposed to backing.

Walker circulation

A name coined by Bjerknes for two circulation cells in the equatorial atmosphere, one over the Pacific and one over the Indian Ocean. Schematically these are longitudinal cells where, on one side of the ocean, convection and the associated release of latent heat in the air above lifts isobaric surfaces upward in the upper troposphere and creates a high pressure region there. The lack or lesser degree of the same process on the other side of the ocean results in lower pressure there, and a longitudinal pressure gradient is established which, being on the equator, cannot be balanced by the Coriolis force. Thus a direct zonal circulation is driven in the equatorial plane with countervailing winds at the surface and in the upper troposphere, with concomitant rising and sinking branches on the appropriate sides of the ocean.

The normal Walker circulation in the Pacific consists of air rising over Indonesia, west winds in the upper troposphere, sinking air off the west coast of South America, and east winds near the surface. A reversed but weaker Walker circulation and an enhanced Hadley circulation occurs during ENSO years. In the

Indian Ocean the circulation cell proceeds in the opposite sense (to the normal Pacific Walker cell), with sinking air over cold waters off the Somali coast and a low-level acceleration from west to east along the equator in the lower atmosphere. The figure below indicates the Walker circulation. Red arrows shows the circulation during normal year and the blue arrow indicates the El Nino year. Please note the east ward shift of the circulation during el Nino year.



Water mass

In physical oceanography, it is a body of water with a common formation history. A water mass is identified through relationships on a T-S diagram, although additional information about the degree of spatial and temporal variability during its formation as expressed by a standard deviation is almost always needed as well. A single T-S point, i.e. a water type, along with its standard deviation, may be sufficient for identification (especially with deep water masses), although generally a set of T-S combinations, i.e. a function in T-S space, is needed along with a standard deviation envelope. Generally the standard deviation decreases with depth. In practice not enough data is usually available to calculate a standard deviation, so a point or line in T-S space is specified around which the water mass properties are presumed to vary.

Water mass characteristics

A property value or, more often, range of property values by which water mass can be identified and tracked through the ocean. The most commonly used are temperature, potential temperature, salinity, potential density, or the density referenced to a particular depth or pressure. Less often used but still quite valuable for certain applications are oxygen, nitrate, phosphate, silicate, chlorofluorocarbon, carbon 14 and tritium.

Water type

In physical oceanography, a point on a T-S diagram. It has a single value of temperature and salinity.

Weather

Local and short period changes in atmosphere is called weather and long period changes of a place is called the climate. The weather, as distinguished from the climate, consists of the large fluctuations in the atmosphere from hour-to-hour or

day-to-day. These occur as weather systems move, develop, evolve, mature and decay as forms of atmospheric turbulence. Weather systems originate mainly from atmospheric instabilities and their evolution is nonlinear, making them unpredictable beyond a week or two into the future. They most likely never will be predictable beyond that due to the inherent properties of systems governed by chaotic dynamics.

Western boundary current (WBC)

It is the intensified western limb of an oceanic circulation gyre. This is inevitable given a rotating earth, a meridional boundary, and a zonal wind stress pattern that reverses direction at some latitude as was shown using a simple dynamical model in the classic paper of Stommel (1948). Common features of such currents include their flowing as swift narrow streams along the western continental rise of ocean basins, their extension to great depth well below the thermocline, and their separation from the coast at some point and continuation into the open ocean as narrow jets that develop instabilities along their paths. The most well-known western boundary currents are the Gulf Stream and the Kuroshio Current.

WOCE

Acronym for the World Ocean Circulation Experiment program, a component of the WCRP that is a cooperative scientific effort by more than 30 nations to provide essential strategic research on ocean circulation. The primary goals of WOCE are (1) to develop models useful for predicting climate change and to collect the data necessary to test them and (2) to determine the representativeness of the specific WOCE data sets for the long-term behavior of the ocean, and to find methods for determining long-term changes on time scales from ten to one hundred years. The field phase of the program is from 1990 to 1997 and the analysis, interpretation, modeling and synthesis (AIMS) phase continues until the year 2002. Some WOCE observations will be continued by the CLIVAR program.

World Meteorological Organization

A specialized agency of the United Nations encompassing the field of meteorology. It replaced the IMO (International Meteorological Organization) in 1951. The purposes of the WMO are to facilitate world-wide co-operation in the establishment of networks of meteorological observation stations and to promote the development of centers charged with the provision of meteorological services; to promote the rapid exchange of weather information and the standardization of meteorological observations and their publication; to further the application of meteorology to human activities and to encourage research and training in meteorology..

Yanai wave (Rossby wave)

An equatorially trapped wave that behaves like a mixture of gravity and Rossby waves. Yanai waves exhibit an eastward group velocity at all wave numbers k , although for large positive k it behaves like a Rossby wave and for large negative k like a gravity wave. For the case $k=0$ it is a standing wave for which the surface moves sinusoidally up and down with opposite sign on opposite sides of the

equator. Fluid particles move anticyclonically around elliptical orbits. With eastward motion when the surface is elevated and westward motion when it is depressed. To be completed.

Zenith angle

The angle between the local normal to the Earth's surface and a line between a point on the Earth's surface and the sun.

Zonal mean wind

The horizontal component of wind blowing along the latitude or east ward is called the zonal mean wind. The distribution of the zonal mean of the eastward component of the wind through latitude and height. This is westerly through most of the troposphere, and peaks at speeds exceeding 30 m/s in the subtropical jet stream. Near the surface the zonal mean winds are westerly at most latitudes between 30 and 70 °, with easterly winds prevailing at latitudes less than 30 °.

Zoppritz, Karl

A German fluid dynamicist who was a pioneer in applying modern fluid dynamical methods to questions of the large-scale oceanic circulation.